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ORIGINAL

TRAINING COURSE

SKID RESISTANCE MEASUREMENTS AND DESIGN

COMPLETED
311

INSTRUCTOR NOTEBOOK

CONTRACT DTFH61-80-C-00023

PREPARED FOR THE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
NATIONAL HIGHWAY INSTITUTE

BY

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FALLS CHURCH, VIRGINIA

1981

Use Of Instructor Notebook

This notebook contains all of the material in the Participant Notebook with notes to instructors added. The numbered pages are reproduced directly from the Participant Notebook. The pages that are not numbered are not contained in the Participant Notebook.

Each session of this notebook begins with an Instructional Guide, which includes equipment and visuals aids required, a suggested approach to teaching that session and major points to emphasis. The Participant Notebook is printed with a wide margin to facilitate note-taking. In the Instructor Notebook, that margin is used for notes to the instructor on visual aids to use and other helpful hints.

Visual aids are numbered with either a "V" or "S" and a 4-digit number. "V" denotes view-graphs and "S" 35mm slides. The first two digits indicate the session number and the last two digits is a sequential numbering of the aids within each session. Each view-graph is reproduced at the end of each session and each 35mm slide is described in the indicated instructional aids. The reference films should be available in FHWA regional office lending libraries or the National Highway Institute.

SKID RESISTANCE MEASUREMENTS AND DESIGN
DTFH61-81-C-00023

LIST OF SESSIONS

NO	SESSION TITLES
11	INTRODUCTION TO COURSE
12	THE SKID ENVIRONMENT AND WET WEATHER ACCIDENTS
13	VARIATION IN FRICTION DEMAND (NEEDS)
21	SKID RESISTANCE MEASUREMENTS AND THE WET PAVEMENT ACCIDENT REDUCTION PROGRAM
22	DETECTION OF SLIPPERY CONDITIONS - ACCIDENTS, CITIZEN REPORTS, AND VISUAL INDICATIONS
23	DETECTION OF SLIPPERY CONDITIONS - SKID TESTING
24	SKID TEST EQUIPMENT CALIBRATION AND CORRELATION
31	FACTORS AFFECTING SKID RESISTANCE - MATERIALS
32	FACTORS AFFECTING SKID RESISTANCE - PAVEMENT
33	FACTORS AFFECTING SKID RESISTANCE - SEASONAL, CONTAMINATION, ROAD ROUGHNESS, AND OTHERS
41	METHODS OF RESTORING SKID RESISTANCE - OVERLAYS
42	METHODS OF RESTORING SKID RESISTANCE - GROOVING AND TEXTURING
51	THE USE OF SKID TEST DATA IN THE DESIGN AND DEVELOPMENT OF SPECIFICATIONS FOR SKID RESISTANT PAVEMENTS
52	DESIGN OF NEW PAVEMENTS
53	TEXTURING NEW PAVEMENTS: GROOVING, METAL TINES, BURLAP DRAG, WASHING AWAY MORTAR, AND BRUSHING
61	LEGAL IMPLICATIONS OF HIGHWAY SKID RESISTANCE

SESSION 11

INSTRUCTION GUIDE

EQUIPMENT - 16 mm Projector, Overhead Projector

AIDS: Viewgraphs 1101-1107
Film: Wright subcommittee film on "wet weather skidding accidents".

PRESENTATION

Registration, welcome, introduction:

TEACHING AID 1101

SEQUENCE OF ITEMS FOR SESSION 11

Introductions

1. If appropriate, the course may be introduced by a guest from the sponsoring agency.

2. The instructors will introduce themselves by giving a brief resume of their qualifications, background and experience relevant to skid resistance. The purposes are to:

   - Establish your credentials
   - Create a personal image with which participants can relate, and
   - Let the class know what your vantage point is.

3. State that there is a great deal of material available to the instructors and that this session will be used in part to define the subject matter to be included and emphasized during the course. Therefore, each participant will be asked to introduce himself and provide information that indicates his background and objectives in taking the course.

4. Going systematically around the classroom, ask each participant to share with the class the following information:

   - Name
   - Agency,
   - Title or position,
   - Responsibilities related to skid resistance and
   - Role that he may play in the development and operation of skid resistance programs.

5. It may be useful for the instructor to summarize on the blackboard the cross-section of the class (e.g. number in materials highway maintenance, pavement design, skid testing, etc.).

6. The instructor should use this opportunity to ask participants leading questions which will help him in deciding what should be covered in this course and the best way to exercise the several teaching options available.

Optional speech of welcome by course coordinator, senior member of host agency, or senior member of instructor firm.

Introduction 1. Self introduction by course instructors
2. Self introduction by participants

Courses Registration and Evaluation

1. Registration cards
2. FHWA standard form.
3. Session by Session Evaluation sheets
4. Mention Evaluation Questionaire to be handed out at end of course.

Objectives of Session

Film - Brief Description of Wright Subcommittee Film on Skidding Accidents

The short film you are about to see was developed for the Wright Subcommittee of the Blatnik Committee, formed to investigate hazards built in or subsequently developed in the interstate system. This film shows skidding vehicles at the Capital Beltway and I-270 junction. The illustration demonstrates what can happen when a number of negative factors, including slippery pavement, come together. Later in this course different factors causing skidding will be discussed.

Discuss the film pointing out other factors apart from pavement which may affect accidents shown in the film, e.g. vehicle testing procedures in Maryland, vehicles having defective tires, etc.

Lead into the complexity and interrelationships of all factors affecting skid. Use V-1101 as the overall viewgraph of the course.

Lead into the Participant Notebook.

SESSION GUIDE

SESSION: 11. INTRODUCTION TO COURSE

SESSION OBJECTIVES:

Participants will identify their purpose and objectives in attending the course and demonstrate their ability to actively participate in session discussions. They will become acquainted with their fellow students and instructors. They will be introduced to the subject matter of the course and become familiar with the history, background and reasons for skid resistance measurements and design. In addition the participants will become familiar with the course format, procedures and schedule.

REFERENCES: 1, 2, 3

CONTENT:

Registration, Welcome, Introductions - Including Brief Backgrounds of Work Experiences, Especially Those Related to the Course Content.

Purpose and Objectives of the Course 11-2

Course Format and Procedures 11-3

Introduction to Skid Resistance Measurements and Design 11-3

Frictional Requirements 11-7

Lasting Effects of Traffic on Pavements 11-10

Movie - Wright Subcommitee "Film on Wet Weather Skidding Accidents."

PURPOSE AND OBJECTIVES OF COURSE

Purpose of the Course

The purpose of this course is to train professionals and technicians in the transportation field charged with the responsibility of providing adequate levels of skid resistance. It is intended to increase the knowledge and understanding of those who conduct and supervise skid measurements; of those who restore adequate levels of skid resistance; and, of those who develop and provide specifications for skid resistant pavements. It is also meant to help administrators who make decisions on skid test program development and skid test inventories.

Discuss purpose of course

Since all areas of the public sector are subject to litigation due to the erosion of sovereign immunity, the legal ramifications of skid resistance are included in the course.

Objectives of Course

Upon completion of the course the participants will:

- Have an understanding of the factors that determine the skid resistance of pavements;
- Be familiar with methods of detecting slippery pavement conditions;
- Be familiar with skid testing methodology, and the development and implementation of a statewide skid testing inventory program;
- Be familiar with skid test equipment calibration and correlation;
- Have knowledge of several methods to restore skid resistance to slippery pavements;
- Understand how the skid resistance properties and performance of existing pavements may be used in the design of new pavements;
- Understand how pavement texture and texturing on both new and old pavements affect skid resistance;

Discuss what the students are expected to get out of the course using key words.

Examples:

- *Understand factors,*
- *Detection of slippery conditions,*
- *Etc.*

V-1102

- Be familiar with design elements necessary to produce pavements with high levels of skid resistance;
- Be aware of the legal implications of skid resistance.

COURSE FORMAT AND PROCEDURES

Course Format

The course is separated into six major areas. These areas when completed will produce a comprehensive and thorough treatment of the subject of skid resistance measurements and design. The session numbers and areas are:

Discuss major areas of course utilize viewgraph

V 1103

Sessions 11-13,	INTRODUCTIONS AND BACKGROUND
Sessions 21-24,	WET PAVEMENT ACCIDENT REDUCTION PROGRAM AND DETECTION OF SLIPPERY CONDITIONS
Sessions 31-33,	FACTORS AFFECTING SKID RESISTANCE
Sessions 41-42,	METHODS OF RESTORING SKID RESISTANCE.
Sessions 51-53,	NEW PAVEMENTS AND SKID RESISTANCE
Session 61,	LEGAL IMPLICATIONS OF HIGHWAY SKID RESISTANCE

Procedure

Instruction for each session will include a brief discussion of the objectives and a lecture by the instructor. This will be followed by an in-depth discussion of the subject matter with emphasis on participation by members of the class and the instructor(s). Visual aids will be used throughout the course to enhance understanding and clarity of the subject matter. Instructors will close each session with a brief summary of major and pertinent points.

Insert Wright subcommittee film on skidding- brief description of film on opposite page

INTRODUCTION TO SKID RESISTANCE MEASUREMENTS AND DESIGN

Skid Resistance

Skid resistance is the force developed when a tire that is prevented from rotating slides along a pavement surface. More commonly, skid resistance is thought of as a pavement property; it is the opposite of slipperiness. It is in this sense that

Begin the development of the definition of skid resistance by asking several members of the class for their definition. Then follow up their definition with the text book definition.

skid resistance is used in this course. The term, therefore, does not have a precise meaning, and permits one to describe a pavement surface in the most general way.(1)

History

Although the skidding problem, in one form or another, has prevailed for many years, its threat to human lives was not seriously considered until the advent of the automobile. At this time miles of hard-surfaced, high-speed highways were available to the motorist.

Good background but not necessary to stress in detail

The skid resistance of pavements has been a topic of concern among the highway community for many years. As far back as the 1930's, Ralph Moyer of the Highway Research Board and others became distressed about the potential safety problems relating to skid resistance and conducted research on skid conditions and measurements.(2)

Even before the 1930's research on the skid resistance of road surfaces had begun in England. In 1927 the first skid-resistance research was conducted at the National Physical Laboratory, later to become the Transport and Road Research Laboratory. Early equipment consisted of a specially designed motorcycle and sidecar.

In 1958, the First International Skid Conference held in Virginia was the initial major effort to bring together the many engineering and research aspects of the subject. During that conference emphasis was placed on the definition of problems and the identification of research needs associated with skid resistance.

During the intervening years, numerous techniques have been developed for reducing wet-weather accidents. Most of the basic mechanisms and interactions involved are known, and many promising solutions have been identified and demonstrated.

The Second International Skid Prevention Conference, held in Columbus, Ohio in 1977, was organized to facilitate an international exchange of information of the aspects of wet-weather skidding accidents on highways. Primary emphasis was placed on research results and their application, vehicle industry developments, and operating agency practices and programs known to have a significant influence on reducing wet weather accidents.

Since a sizable portion of the material in this course came from this conference the proceeding should be mentioned as being included in Transportation Research Records 622,623, and 624.

Why Skid Test?

The ultimate safety failure of a transportation system is the occurrence of an accident, especially one resulting in a personal injury or fatality. There are a great number of causes of accidents. Wet weather accidents are much more frequent than dry weather accidents for equivalent time periods. At certain high accident sites, the wet-weather accident rate may be 10 to 20 times the dry-pavement accident rate. This suggests that there are negative factors operating during wet weather that are not present at other times. Some of these factors are reduced visibility, increased glare from oncoming vehicles, different behavorial patterns by vehicle operators, etc. These are all important factors and will be treated comprehensively elsewhere.

Important information. Lead class in discussion.

Brief discussion of how accident rates vary from dry to wet conditions.

There are several ways of detecting slippery pavements, but the principal method before an accident occurs is by skid testing. So the primary reason for skid testing is to detect slippery conditions before accidents occur and so that corrective action may be taken. Another reason is to evaluate sites with high wet weather accidents and to establish pavement history for accident reconstruction.

Discuss the reasons why skid testing is the desirable way to detect slippery conditions

Pavement Slipperiness

The force transmission between a slipping or skidding tire and a dry or wet pavement surface is a frictional process. All frictional processes have a common factor: The developed friction is a function of the material properties of both bodies in sliding contact and prevailing operational conditions.

Cover frictional process and factors affecting skid resistance

Pavement slipperiness and pavement skid resistance are not pavement properties alone, but are also affected by tire properties and operational factors.

When the term slippery pavement is used further clarification is necessary. Although it is generally true that a slippery pavement is conducive to skidding accidents, it is by no means correct to assume that a skidding accident automatically indicates pavement slipperiness. Skids that are due to excessive speed, smooth tires, unbalanced brakes, poor geometric design of the highway, rough or inattentive driver, are not due to pavement slipperiness. On the other hand, skids that take place at normal traffic speeds with well-treaded tires and vehicles in good mechanical condition - particularly if they recur at the same location - most definitely suggest pavement slipperiness. Thus, when the term slippery pavement is used it is with the understanding that all other factors involved are normal, or nearly so, and that they do not significantly contribute to any skidding which might occur.

The principal and partly unsolved problem areas of pavement slipperiness are as follows:

Discuss pavement slipperiness problems using viewgraph 1104

- Measurement of pavement friction, particularly on non-tangent locations such as intersections and curves.
- Universal acceptance of skid resistance requirements.
- Development of techniques which permit the design of specific friction levels into new pavements.
- Reconditioning of slippery surfaces.
- Textured pavements with adequate durability.
- Knowledge of pavement wear and aggregate polishing interactions.

Pavement Friction

To achieve the objective of reducing or eliminating pavement slipperiness, one must first be able to accurately measure the friction level of pavements under controlled conditions. Advances in the accuracy and reliability of friction test equipment are encouraging but the present approach leaves much to be desired. This statement is based on the following:

Omit or touch upon lightly in lecture

1. In both Europe and the United States skid resistance has become the accepted method of rating pavements for slipperiness, despite the fact that, on the basis of vehicle - miles traveled, tires operate almost exclusively in the slipping mode. Stated in another way, the condition measured is precisely what it is sought to keep the motorist from.

2. Skid measurements, including those taken with the most accurate testers, have only relative significance because the measured friction values are influenced by test equipment, tire characteristics, water film, and operating conditions, in addition to the pavement skid resistance.

3. The measurements are affected by conditions beyond the test engineers control, that is, by factors which may vary. Thus, the frictional comparison of several pavements, or the same pavement at different times, measured by the same person, equipment, and under identical conditions do not always correlate.(2)

FRICTIONAL REQUIREMENTS

The measurement of pavement friction is, in itself, of limited value as long as the frictional needs of traffic are unknown. It is this need which provides that yardstick for the rating of pavement surfaces as being either slippery or skid resistant.

This discussion should emphasize frictional requirements, the establishment of realistic requirements, and the difficulty associated with establishing requirements.

Realistic frictional requirements must be established from demonstrated, rather than assumed needs of traffic, and they must include economic considerations.

The difficulty associated with arriving at a realistic standard is that frictional requirements are not the same for all highway traffic conditions. They are a function of roadway geometry, vehicle design, and driver habits, the last being a particularly elusive variable.(3)

Suitable methods of measuring friction, in combination with the frictional demand required by traffic, permit the rating of pavements as slippery, marginal, or safe. However, they leave open the question of how frictional improvements are to be brought about.

Principal Causes of Pavement Slipperiness

Pavement slipperiness arises from the presence of water in the tire area; from increased vehicle speeds which lower the frictional availability and raise the frictional demand; and from higher traffic densities which, through pavement wear and aggregate polish, drastically reduce frictional availability of new pavement surfaces.

The principal causes of pavement slipperiness should be discussed using viewgraph 1105

Substantial advances have been made in producing skid resistant pavements. Much research has gone into the design of pavements to reduce water at the tire-pavement interface, with promising results. Speed limits have been reduced, and, in general, motorists are driving at slower speeds. The use of aggregate blends to provide good pavement mixtures with higher skid resistance values not susceptible to polishing is becoming more commonplace. A major problem is obtaining an adequate supply of polish resistant aggregate. There are large areas in the United States where the only aggregate sources are carboniferous (limestone) and metamorphic rocks such as schists and gneisses which are not suitable.

Correction of Slippery Conditions

When slippery pavement conditions are detected, the job of correcting them must be accomplished. The primary ways of restoring skid resistance are:

Do not discuss too deeply-major topics later in the course.

- Resurfacing,
- Texturing.

These are major topics that will be discussed during the course.

Characteristics of Skid-Resistant Surfaces

An ideal pavement would have the following characteristics, which are not necessarily all compatible with one another:

Ideal characteristics of a pavement should be discussed using viewgraph 1106.

- High skid resistance - ideally the skid resistance when wet would be as high as that of the dry pavement.
- Little or no decrease of vehicle skid resistance with increasing speed - the skid resistance of dry pavements is nearly independent of speed, but this is not so on wet pavements.
- Little or no reduction of skid resistance with time, as from polishing or other causes.
- Resistance to wear - by abrasion of aggregate, attrition of binder or mortar, loss of particle, etc., even when exposed to traffic using studded tires.

- Structural durability - ability to maintain initial load carrying capacity.
- Low noise generation.
- Low cost - lowest life-cycle cost which provides acceptable levels of service.
- Low tire wear and rolling resistance.
- Little or no splash or spray.
- Provide acceptable levels of ride quality.
- Adequate macro - and microtexture to match functional demands.

Why Pavements Lose Skid

Pavements subjected to traffic and environmental degradation lose surface micro and macro-texture. The loss of pavement texture in turn has the major impact on reduction of skid resistance. Compounded with this, pavements which develop wear in the wheel tracks provide an area for water ponding and aggregate polishing, both of which induce lowered friction values.

Discuss loss of skid resistance in relation to texture.

The Effect of Tires

The tires scrub and squirm. When a tire rolls, some of the tread elements in the tread area move relative to the pavement surface. Once a tread element moves it tends to cause abrasion and changes in the surface characteristics of the aggregate particles. These phenomena are amplified when torque is applied to the tire, whether it is to maintain constant speed, or to accelerate and decelerate.

Studded tires are another component that is destructive to pavement surfaces. As a stud contacts the pavement it slams into the surface with great speed and force. This is also the case with tread elements, but since they are resilient this is not serious, although tread design contributes to the noise that tires generate.

LASTING EFFECTS OF TRAFFIC ON PAVEMENTS

The lasting effects that traffic can have on a pavement fall into three broad categories:

Brief mention of the lasting effects of traffic on pavements.

- Changes in pavement structure,
- Wear, and
- Polishing

Specifically pavement skid resistance is lowered by:

The remainder of chapter deals with how skid resistance is lowered. Discuss each point using viewgraph V 1107.

Wear

A process whereby the top layer of pavement is removed or altered by traffic. It is usually a gradual, continuous process and is very much a function of aggregate characteristics, mixture properties, and amount and type of traffic. However, aggregate wear is the primary characteristic of skid resistance which can be partially considered in design.

Polishing

A process where the microtexture of aggregates and pavements is reduced. Minerals do not deform plastically to any significant extent; and, therefore, polishing requires the removal of material, albeit in very small increments. Polishing and wear are greatly accelerated by the presence of an abrasive.

On the road, most of the polishing probably takes place while the pavement is dry, because pavements are dry most of the time.

Traffic volumes are the governing factor in the polishing process. This was clearly demonstrated when one type of surface course was installed at six different locations. Traffic volumes varied from 10,000 to 50,000 average daily traffic (ADT). When the skid resistance was measured three years later the skid numbers varied from a high 55 for 10,000 ADT to 38 for 55,000 ADT.

Bleeding of Asphaltic Concrete Pavements

A situation where the texture is lost due to the asphalt binder becoming viscous enough to flow, thus covering the surface aggregate. A somewhat analogous situation sometimes occurs with new pavements. During the manufacture of the mix the pores of the aggregate are coated with binder material. As traffic wears off this binder coating, the aggregate particles are exposed on the pavement surface. This explains why some newly placed pavements show an increase in skid resistance over an initial time period.

Compaction and Rutting

Compaction of flexible pavements draws binder material to the surface causing contact with the tires. This decreases the overall microtexture of the surface. Compaction also reduces macrotexture. Thus, skid resistance is lowered at all driving speeds.

A result of channelized traffic is that ruts form in the wheelpaths. The ruts fill with water to a greater depth than would be present otherwise. This can lead to hydroplaning and increases in splash and spray, presenting additional safety hazards particularly on heavily traveled roads.

Contamination

It is a generally accepted axiom that pavements are more slippery at the beginning of a light rain than later.

When contamination is heavy, the skid resistance is adversely affected. If oil or another substance with good lubricating properties is present in any significant amount, the tire-pavement interface will be lubricated whether or not there is water, hence friction will be low.

Other contamination may consist of solid windrows of antiskid material left after snow and ice have melted, and similar accumulations of foreign material. As long as the tires roll, such contaminants can be dangerous because the tire rolls onto them causing the particles to act like the balls in a bearing.

Deicing agents are a form of contamination that occurs frequently in cold climates. After ice and snow have been melted by them, the pavement dries, usually slowly because of the prevailing low temperatures. The deicing agents further delay the drying process with an attendant effect on the skid resistance. This is not an indictment of deicing agents, but it does serve as a warning to apply them no more generously than necessary for the job to be done.

Roughness

When a road is rough the vehicle ride also becomes rough. If this causes wheel hop when brakes are applied then skid resistance is reduced.

Cyclic Effects

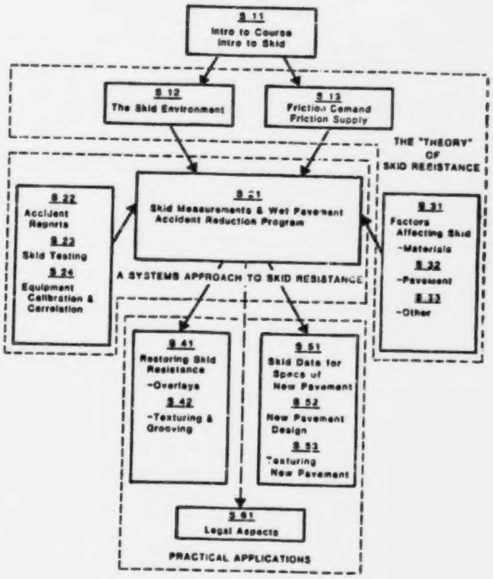
There are differences in the levels of skid resistance that are dependent on seasonal and temperature variations.

Pavement Drainage

Fast removal of the water that rain deposits on pavement is important. On properly designed pavements the asperities of texture protrude through the water film. Changes in pavement contour usually reduce runoff and drying. Rutting and increasing pavement roughness increase localized water ponding and consequently increase the time required for the pavement to dry completely once the rain has stopped, or snow and ice have melted.

Changes in the water depth on a pavement may also occur because water runs onto the pavement such as when drainage ditches overflow, water sheets across the slope of a pavement where it is banked in one direction or when a snowbank melts.

1101


S 11
Intro to Course
Intro to Skid
S 12
The Skid Environment
S 13
Friction Demand
Friction Supply
THE "THEORY" OF SKID RESISTANCE
S 21
Skid Measurements & Wet Pavement Accident Reduction Program
S 22
Accident Reports
S 23
Skid Testing
S 24
Equipment Calibration & Correlation
S 31
Factors Affecting Skid
-Materials
S 32
-Pavement
S 33
-Other
A SYSTEMS APPROACH TO SKID RESISTANCE
S 41
Restoring Skid Resistance
-Overlays
S 42
-Texturing & Grooving
S 51
Skid Data for Specs of New Pavement
S 52
New Pavement Design
S 53
Texturing New Pavement
S 61
Legal Aspects
PRACTICAL APPLICATIONS

1102

OBJECTIVES

Participants Will Have an Understanding of:

- Factors Determining Skid Resistance of Pavements
- Methods of Detecting Slippery Pavements
- Skid Testing Methodology
- Skid Testing Equipment, Calibration and Correlation
- Most Appropriate Method of Skid Resistance Restoration
- Effects of Texture on Skid Resistance
- Design Elements for High Skid Resistance
- Legal Aspects

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Sessions 11-13,	Introductions and Background
Sessions 21-24,	Wet Pavement Accident Reduction Program and Detection of Slippery Conditions
Sessions 31-33,	Factors Affecting Skid Resistance
Sessions 41-42,	Methods of Restoring Skid Resistance
Sessions 51-53,	New Pavements and Skid Resistance
Session 61,	Legal Implications of Highway Skid Resistance

1104

PAVEMENT SLIPPERINESS PROBLEMS

- Pavement Friction Measurement
- Skid Demand
- Design
- Surface Reconditioning
- Wear and Polishing Interaction

1105

PRINCIPAL CAUSES OF PAVEMENT SLIPPERINESS

- Water in Tire-Pavement Contact
- High Vehicle Speed
- Worn Pavement/ Aggregate Polish

1106

IDEAL PAVEMENT CHARACTERISTICS

- High Skid Resistance
- Constant Skid Resistance with Increased Speed
- Constant Skid Resistance over Time
- Wear Resistance
- Durability
- Low Cost

1107

SKID RESISTANCE IS LOWERED BY:

- Wear
- Polishing
- Contamination
- Compaction & Rutting
- Roughness
- Seasonal Variations
- Poor Pavement Drainage

SESSION 12

INSTRUCTORS GUIDE

EQUIPMENT - 16 mm Projector, Overhead Projector

AIDS: Viewgraphs 1201-1207
Film: War on wet weather accidents

OBJECTIVE: An introductory overview of some theoretical concepts of the tire-pavement interface including adhesian and hysteresis, followed by the wet pavement skid resistance relationships.

APPROACH: The session should begin with a general overview of the wet weather skid environment. This should include answers as to why accident potential is greater during wet weather. A briefing on accident statistics, emphasizing wet weather versus dry weather accidents will strengthen the discussion.

Each component of the skid environment should be discussed. Discuss pavements last. Since in this course the emphasis is on pavements and their interaction with tires, at this point the definition and explanation of the terms "Adhesion" and "Hysteresis" need to be discussed.

Do not refer to skid numbers at this stage.

The wet pavement skid resistance relationship between friction, speed, wet pavement and tire characteristics such as angle of slip and percent of slip should be discussed.

SESSION GUIDE

SESSION: 12. THE SKID ENVIRONMENT AND WET WEATHER ACCIDENTS

SESSION OBJECTIVES:

At the end of the session the participants will have gained a clear understanding of the critical tire-pavement interface in skid resistance and the wet-pavement skid resistance relationship.

REFERENCES: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

CONTENT:

The Skid Environment 12-2

The Tire-Pavement Interface 12-2

Adhesion and Hysteresis 12-2

Mechanism of Tire Friction 12-7

Driver Requirements 12-9

Wet Pavement-Skid Resistance Relationship 12-9

Wet Weather Accidents 12-11

THE SKID ENVIRONMENT

The occurrence of skidding is heavily dependent on three major components:

- The Pavement - Surface characteristics.
- The Vehicle - Tires and suspention.
- The Driver - Driving habits and capabilities.

In-depth coverage of the three major components of the skid environment. Using viewgraphs 2101 and 1202.

The external environment, mainly wet weather, can affect each of these components either directly or indirectly. For instance, rainfall affects the friction available from the pavement surface, the tire tread affects the capacity of the tire to remove water at the tire/pavement interface, and wet roads can lead to headlight reflection and spray affecting the driver directly by reducing his perceptual vision and sight distance.

Figure 12-1 illustrates the concepts that the occurrence or avoidance of a skidding accident is an interrelated function of the three major components.

A deficiency in any one of these components, that is, the pavement, the vehicle, or the driver can be the cause of a skidding accident. In this course, we are mainly concerned with the pavement, yet it must be remembered that complex relationships exist between the pavement, the vehicle, and the driver, and each of these can in turn be affected by the external environment.

THE TIRE-PAVEMENT INTERFACE

One of the most important factors in the safe operation of the modern motor vehicle is the development of necessary tire-pavement friction. It is well-known that during an emergency stop, the last chance for avoiding an accident resides with the level of skid resistance developed between the tire and pavement during braking.(4)

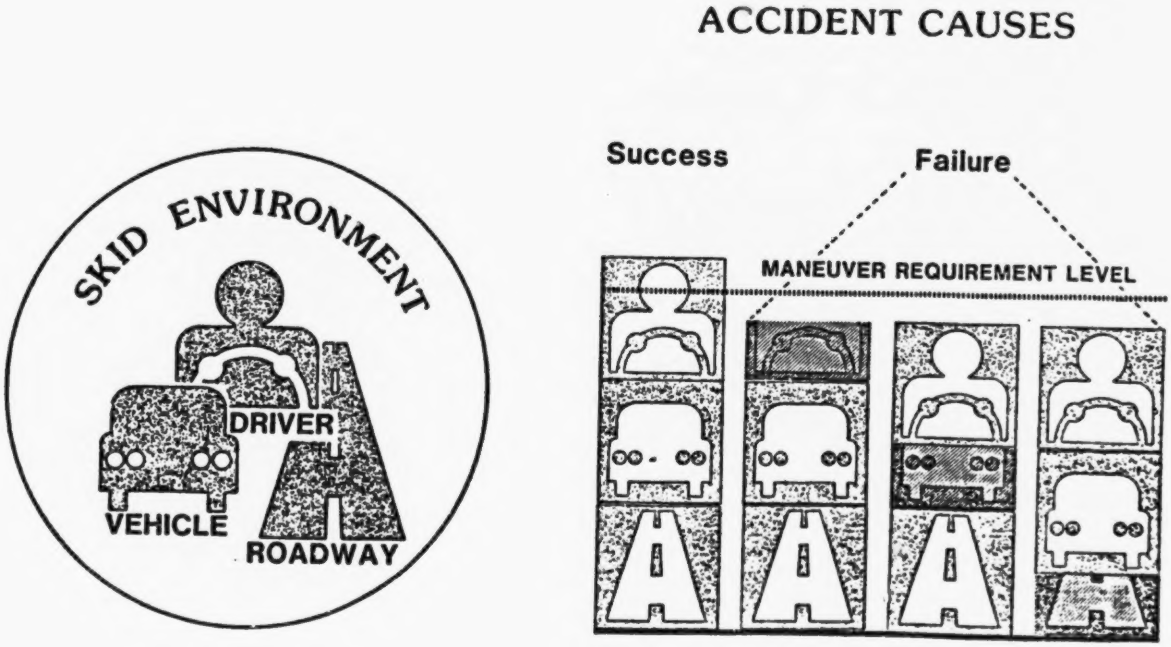
ADHESION AND HYSTERESIS

The interpretation of frictional measurements made on dry and wet surfaces is not an easy task because ultimately frictional processes take place on a molecular scale, and a multitude of surface, rubber, tire, vehicle, and operational factors affect the magnitude of the generated friction.(3)

Adhesion and hysteresis should be discussed and participants should gain an understanding of the principal, but an in-depth scientific definition should be avoided.

FIGURE 12-1

THE SKID ENVIRONMENT AND ACCIDENT CAUSES


ACCIDENT CAUSES
SKID ENVIRONMENT
DRIVER
VEHICLE
ROADWAY
Success
Failure
MANEUVER REQUIREMENT LEVEL

The two principal factors responsible for rubber friction are adhesion and hysteresis. In the absence of wear the measured frictional force is the sum of the adhesion force and hysteresis force. The adhesion component is generally considered to be the product of interface shear strength and contact area.

Adhesion and Hysteresis should first be introduced together using viewgraph 1203 (Figure 12-2)

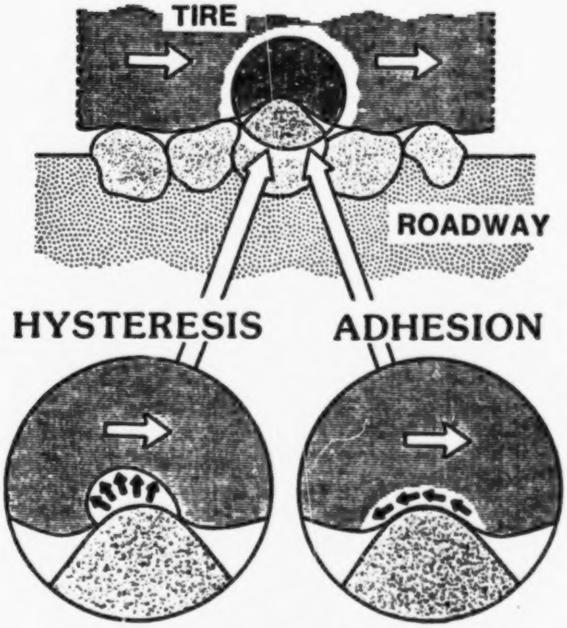
The hysteresis component (hysteresis is a heat loss which manifests itself as a force) is caused by damping losses within the rubber when the latter is "flowing" over and around the mineral particle. The damping possessed by the rubber opposes the displacement of the rubber upstream of the obstacle, as well as the downstream recovery, thus producing an unsymmetrical pressure distribution.

Use examples to demonstrate the concepts of adhesion and hysteresis.

As an example, adhesion is comparable to the force developed when a hand slides over the smooth surface of a desk. Adhesion is a microtexture interaction. If a paperweight is on the desk and the hand runs into it, the forces developed as the hand slides into, over, and out of contact with the paperweight are analagous to the forces causing energy absorption by the tire through hysteresis. Hysteresis is a macrotexture phenomenon that occurs when the tire is deformed by projections in the pavement, such as semi-exposed aggregate particles, and in the process absorbs energy.

The concepts are illustrated in Figure 12-2.

FIGURE 12-2
TIRE HYSTERESIS AND ADHESION



When a pavement is covered with a layer of water, two events must occur in order for hysteresis and adhesion to exist:

1. The macrolayer of water must be expelled from the tire-pavement interface in order for the tire to be deformed by pavement macrotexture. The avenues for this water to escape are formed by the valleys of the pavement macrotexture and by the openings in the tire tread. As the speed of a vehicle increases, the time available to expel the macrolayer of water decreases. When there is no longer enough time to move the layer of water from underneath the tire, dynamic hydroplaning occurs and the tire is planing on a surface of water.

2. The film, or microlayer of water, that remains on the pavement after the macrolayer has been expelled, must be squeezed aside or penetrated by sharp aggregate projections so that adhesion between rubber and pavement materials can occur. As the speed of the vehicle increases, the time availalbe to squeeze the film of water away from the aggregate particles decreases, and the available friction decreases due to loss of adhesion.(5)

Factors Concerning Adhesion and Hysteresis

The major points concerning adhesion and hysteresis coefficients are as follows:

Adhesion -

- On a dry surface the adhesion coefficient is small at creep speeds.

Use viewgraph 1204 in the discussion of adhesion.

- The adhesion coefficient increases rapidly with sliding speed and reaches a maximum at a "critical" sliding speed, which may vary from 0.1 to 10 mph [0.16 to 16 km/hr.] depending on rubber composition and contact area temperature.

- The adhesion coefficient drops when the critical speed is exceeded.

- The adhesion maxima and critical sliding speeds at which they occur are dependent upon the elastic and damping properties of the rubber.

- For any given sliding speed the adhesion coefficient may increase, decrease, or remain unaffectd by temperature changes.
- The adhesion coefficient decreases as the loading pressure increases because of the less than proportional growth of the actual contact area with pressure.
- The adhesion coefficient is very sensitive to contamination and reduces to a small, speed-independent value when the surface is lubricated with oil or water. This drastic reduction is due to the weakening of the shear strength in the contact area. The residual coefficient reflects in part the small amount of hysteresis which is due to the microscopic roughness that even very smooth-looking surfaces possess.

Hysteresis

Use viewgraph 1205 in discussing hysteresis.

- The hysteresis coefficient shows little speed dependence in the range in which adhesion is very speed sensitive.
- The hysteresis coefficient begins to increase noticeably as the sliding speeds become very high (50 mph or 80 km/hr.)
- The hysteresis coefficient increases with the internal damping properties of the rubber, providing the corresponding rubber hardness remains unaffected.
- For any chosen sliding speed the hysteresis coefficient is, much like the adhesion coefficient, temperature sensitive; but unlike adhesion, it always decreases as the rubber heats up at the speeds at which motor vehicles operate.
- The hysteresis coefficient is practically pressure independent.
- The hysteresis coefficient shows little sensitivity to contamination and lubrication.(3)

MECHANISM OF TIRE FRICTION

The tire tread elements in contact with the pavement surface can be regarded as individual rubber blocks connected to a common base, the tire carcass. The measured tire friction is due to the combined action of adhesion and hysteresis.

For any given rubber and surface contact the highest friction coefficient is obtained when the surface is dry and clean and when the sliding speed is "critical" (0.1 to 10 mph [0.16 to 16 km/hr.] depending on rubber composition and contact area temperature). Linking together several rubber elements subjected to the same loading and sliding in the same direction does not affect the frictional coefficient. If the surface is dusty, the shear strength is weakened and a noticeable reduction of adhesion results. The reduction is even more pronounced when the surface is wet.

Emphasize that highest friction is obtained when pavement surface is dry and clean and when the sliding speed is critical.

Skidding

The simplest tire operating mode is when a tire slides or skids in a straight line where all tread elements slide with the same velocity in the same direction. Assuming that the operating conditions are identical for all elements the tire "skid resistance" is equal to the frictional coefficient of a single tread element.

Identify and clarify different tire operating modes that may occur during skidding.

Actually, the assumption of identical operating conditions is not justified for two reasons. First, the pressure distribution in the tire-pavement contact area is not uniform. The center area portion of the tire in contact with the pavement is subjected to much higher pressures than the leading and trailing portions because the deflection of the stiff tire carcass adds to the inflation pressure.(6) Secondly, on wet pavements the tread elements operating near the foot print entrance experience a thicker water film than the trailing ones.

In short, the frictional contribution made by the individual tread elements is not uniform. This is due to the differences in the pressures to which the elements are exposed, which develop different frictional forces and tread element temperature. Also individual tread elements are not uniform because of the greater fluid film thickness near the foot print entrance which drastically lowers the shear strength of adhesion and, at speeds above 30 mph, (50 km/hr.) the deformation volume of hysteresis as well.

Taking into account the different operating conditions which exist in tire contact, while avoiding the cumbersome words "skid resistance coefficient," the term "skid number" (SN) was proposed and defined as the ratio of the skid resistance F of a given tire pairing to the load L, acting on the tire times 100, or

$$SN = 100\ F/L$$

Multiplication by 100 allows the expressing of the skid resistance as a percentage of wheel load. Thus a skid number of 63 percent of the wheel load.

On a dry surface the skid number is small at creep speeds, reaches a maximum at a critical sliding speed, and decreases thereafter. The decrease is accompanied by chatter, which sometimes is audible as "tire squeal." It is obvious that the highest skid number can be obtained only by sliding the tire at the critical speed at which the majority of the tread elements generate maximum friction.

Under wet conditions a vehicle on which the wheels are locked at 50 mph (80 km/hr.) may experience very low friction for three reasons. First, the sliding speed is above the critical speed and adhesion is below its maximum, as it would also be on a dry surface. Secondly, hydrodynamic effects drastically reduce adhesion and hysteresis of all tread elements, particularly of those near the footprint entrance. Thirdly, higher sliding speeds generally produce higher temperatures which in turn reduce damping.

Cover very lightly

Slipping

The sliding speed of the tread elements of a skidding tire is equal to the translatory or skidding speed of the vehicle. In contrast, the sliding speeds experienced by the tread elements of a slipping tire are generally small in relation to the vehicle speed. That the tread elements must slide to transmit substantial friction forces follows from the behavior of the adhesion coefficient which initially increases with sliding speed. This statement is true regardless of whether the tire transmits braking, driving, or cornering forces, or is said to operate in the "brake," "drive," or "cornering slip mode."

Compare skidding to slipping

The friction mechanism of the slipping tire differs from the skidding tire in that the tread elements move at different sliding speeds and in different directions, in addition to experiencing different pressures, temperatures, and fluid films.

DRIVER REQUIREMENTS

The tire-pavement factors in skid resistance, and especially the pavement factors, are of prime concern in this training course. However, to exclude at least a superficial coverage of the part that the driver plays in the overall skid environment would be a serious omission. Although a slippery pavement is conducive to skidding, it is by no means correct to assume that a skidding accident automatically indicates pavement slipperiness. Skids may be caused by excessive speeds, and "rough" or inattentive drivers jerking the steering wheel or slamming on the brakes.

Briefly discuss the part that driver plays in the overall skid environment

Three distinct maneuvers—acceleration, deceleration, cornering, and two combinations of these, acceleration and deceleration while cornering—are required to drive a vehicle. Because the abilities of drivers vary so widely, there is sometimes a mis-match between their capabilities and the functions they are required to perform to drive safely.(5)

It is likely that every driver possesses an individual driving pattern which, much like his signature, reflects his personality. How much driving patterns change from driver to driver in different traffic conditions is not known.

WET PAVEMENT-SKID RESISTANCE RELATIONSHIP

In the transportation field the assumption is made that all dry pavements have adequate skid resistance. Therefore, when skid resistance is referred to, or skid measurements cited, it always means under wet conditions unless specified otherwise. The degree of wetness or water film thickness on pavement will vary depending on:

The wet pavement - skid resistance relationship is the crux of the course and should be covered thoroughly

- The intensity of rainfall,
- The duration of rainfall,
- The pavement drainage, and

- Highway geometrics.

There is evidence that pavements are more slippery at the beginning of a rain than after some duration. This is due to contaminants on the roadway that are washed away after it has been raining for sometime. However, others believe this is due to the delayed adjustment of drivers to the new conditions. At any rate the skid resistances of many pavements do increase somewhat after the initial wetting. One reason could be that in warm weather there is a cooling effect produced on both the tire and pavement which increases the skid resistance obtained from hysteresis.

The water depth on a pavement surface may vary from a trace to complete inundation. Harry Smith states in the Pavement Contributions to Wet-Weather Skidding Accident Reduction, prepared for the Second International Skid Prevention Conference, held May 2-6, 1977 at Columbus, Ohio that:

> "Water depth on a pavement surface has a critical influence on the safe operations of vehicles on pavements. Tire hydroplaning is commonly considered to be the adverse effect from excess water. In actuality, complete hydroplaning, even with smooth tires, is probably a rare occurrence. The vast majority of wet-weather skidding accidents undoubtedly occur as the result of water depths well below those needed for complete hydroplaning."(7)

Research on methods for predicting pavement water depth as a function of rainfall intensity and pavement geometrics has been conducted by the Texas Transportation Institute, the British Transportation and Road Research Laboratory, and the Goodyear Tire and Rubber Company. It was concluded that pavement width (drainage length) and cross slope are the primary roadway factors affecting the drainability of a pavement surface. On a two-lane crowned roadway with a cross slope of 2 (two) percent, a drainage length of 12 feet (3.65 m), and a rainfall intensity of 0.25 in/hr. (6.4 mm/hr.), the computed maximum water depth would be 0.028 inch (0.7 mm). Using the same cross slope and rainfall intensity, the computed maximum water depth for a multilane roadway sloped in one direction only with a drainage length of 34 feet (10.4 m) would be 0.046 inches (1.2 mm).

WET WEATHER ACCIDENTS

Show film - War on Wet Weather Accidents

Discuss the magnitude of automotive vehicular accidents using viewgraph 1206

After the 1973 oil crisis motor vehicle accidents decreased for a period until in 1975 deaths were down to 46,000 nationwide. Prior to 1973 the annual death rate had hovered around the 50,000 figure. Additionally, in 1975 there were 1,800,000 disabling injuries, and the total motor vehicle costs for that year were $21.2 billion.(8) These vehicle costs include wage loss, medical expenses, insurance administration costs, and property damage from moving motor vehicle accidents. Unfortunately, it appears in looking at the 1978 statistics that the downtrend has ended and, in fact, will soon surpass the pre-1973 years. The 1978 statistics show motor vehicle deaths as being 51,500, a 4 percent increase over 1977 and a 12 percent increase over 1975. In 1978 there were 2,000,000 disabling motor vehicle injuries, and the total cost to the nation in 1978 for motor vehicle accidents was $34.3 billion.(9)

Emphasize the proportion of wet weather accidents versus total accidents

Wet weather traffic accidents are estimated to be responsible for about 15 percent of motor vehicle injuries and fatalities. Out of three million annual wet weather highway accidents an estimated 7,500 fatalities and 250,000 injuries occur. Wet weather traffic exposure is very difficult to determine on a national scale. One study indicates that wet pavements exist about 6 percent of the driving time in central Texas.(10)

An accident correlation study in Kentucky indicated that the ratio of wet-pavement accidents to all reported accidents on high speed facilities was between 0.15 and 0.25. Hankins reports the results of a detailed accident investigation and analysis study in which he found that 63.6 percent of all wet-pavement accidents in Texas in recent years were attributable to skidding. Hankins was also able to demonstrate that different accident rates could be attributed to different vehicle maneuver situations. In particular, his data indicates that 40 percent of wet pavement accidents involve a cornering action of the vehicle, where a cornering action is also defined to include passing maneuvers.(11)

In West Virginia the statewide rate for reported accidents is approximately 400 accidents per 100 million vehicle-miles of travel. The statewide wet-pavement accident rate is approximately 650 accidents per 100 million vehicle-miles. Assuming that the roads are wet 15 percent of the time, this is nearly 2.2 times the statewide accident rate on dry pavements, which is about 300 accidents per 100 million vehicle miles.

At certain high-accident sites, the wet-weather accident rate may be 10 to 20 times the dry-pavement rate. For example, 55 accidents were recorded on one curve of the Ohio Turnpike during a four and one-half year period. Of these, 67 percent were reported as skidding on a wet pavement. Kummer and Meyer report a survey of six states where the fraction of wet-pavement accidents attributable to skidding was determined.(3) The results of that survey follow in Table 12-1:

TABLE 12-1

SKIDDING ACCIDENTS AS
PERCENTAGE OF WET-PAVEMENT ACCIDENTS

	1960	1961	1962	1963	1964	1965
Arizona	——	——	1.4	0.5	0	——
Connecticut	17.2	18.2	15.6	19.6	13.6	11.8
Louisiana	32.6	34.1	11.7	13.5	2.4	——
Maine	——	——	——	——	23.4	——
Montana	12.0	7.5	0.7	4.6	1.5	——
Wyoming	——	0.9	1.4	0.9	20.3	——

Vehicle maneuver areas such as at intersections and curves are sites of highest accident involvement. A Virginia study in 1965 revealed that 43 percent of all two-lane traffic accidents in Virginia involved overtaking and/or passing and that approximately 50 percent of them were attributable to skidding.

From a study in New Zealand the following wet-weather accident results were revealed:

- The accident rate while raining was four times that of the clear weather rate.
- The main types of accidents which increased during wet weather due to road surface conditions were head-on collisions, rear end collisions, cornering and loss of control on straight roadway segments.
- The accident types were those most usually associated with slippery road surfaces and/or worn tires.
- Collisions with obstructions, rear end and pedestrians increased at night during wet weather but not during day light wet weather.

Information good for overview of accident situation in wet weather.

It becomes clear after studying reports from around the world that wet-weather accident rates are several times higher than dry-pavement rates. Many studies over the years have attempted to quantify the relationship of wet surface accident frequency with surface friction. Generally, these investigations have not taken account of wetness exposure because wet surface records are not available unless an accident occurs. Even if weather records are available, they are usually for precipitation quantities and not wet surface time duration.

Another problem encountered by researchers is that of obtaining enough accident data to provide reliable estimates of wet accident incidence at a given location. Examination of a few high accident locations will not suffice because of the large random fluctuation inherent in accident percentages computed from even moderate sample sizes. Thus, it is not surprising to find that a review of the literature does not produce uniform conclusions on such questions as the relationship of wet accidents to wetness conditions or pavement skid resistance. Indeed, research studies cannot agree on whether or not a "break point" in skid resistance exists below which wet surfaces are hazardous and above which they are not.

The percentage of wet accidents increases as the length (exposure) of wetness increases. This is counterbalanced by pavements with high skid resistance.

Applying the wet time criterion of 0.01 inch per hour (0.25 mm) — the presumed amount of precipitation necessary to resupply loss by evaporation — to summer rainfall gives the result that summer rainfall produces shorter wet times and hence fewer wet accidents.(13)

Discuss wet weather accidents in relation to viewgraph 1207

Emphasizing

- *Surface wet time*
- *Monthly wet time*
- *Seasonal change*

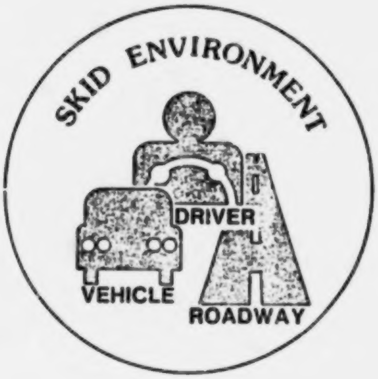
Deal lightly with seasonal change since it is covered in detail later in the course.

Wet time has a profound effect on wet accident incidence, especially in the fall when weather conditions extend the wetted surface time for a given quantity of rainfall. A Michigan study shows that as the percent of wet time increases, the ratio of wet accidents to total accidents increases from 0-14 percent. Holbrook has predicted that the wet accident percentage of total accidents will be nearly 40 percent for a road with a coefficient of friction of 0.20 and 11 percent wet-time.(13) For a coefficient of friction of .60 the wet accident to dry accident ratio is 0.18 for a 14 percent wet time.

The conclusions from the Michigan study were:

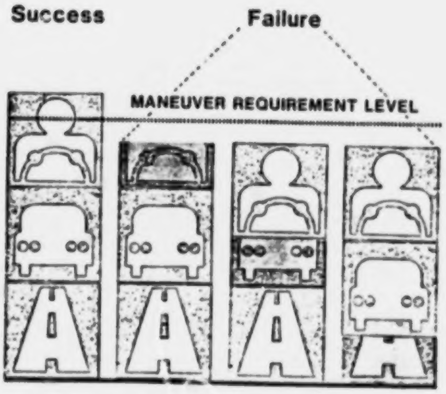
- Surface wet time and skid resistance are important factors in wet accident involvements.
- No critical skid resistance emerged as a point above which wet accident hazard disappeared. Rather, wet accidents appear to be a continuosly decreasing function of surface friction.
- Monthly wet time has considerable effect on wet accident rates.
- Monthly wet time should be included as part of resurfacing decisions. While there are considerable variations from year to year and region to region, a resurfacing policy which takes into account regional and monthly wetness patterns would be valuable.
- A seasonal change of only 12 percent in wet time can have over seven times the impact on wet accident incidence as a 10 unit decline in skid resistance.(13)

1201

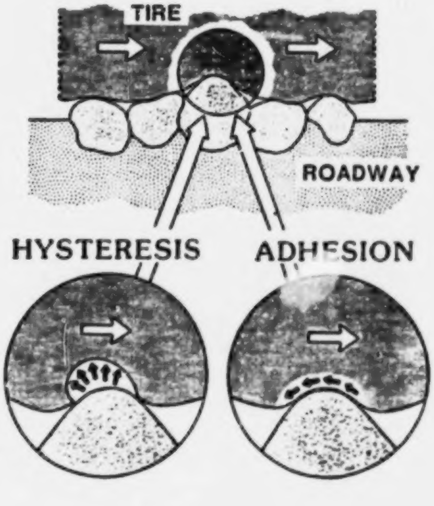

SKID ENVIRONMENT
DRIVER
VEHICLE
ROADWAY

1202

ACCIDENT CAUSES


Success
Failure
MANEUVER REQUIREMENT LEVEL

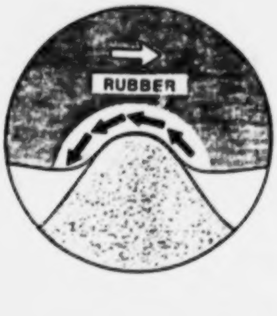
1203


TIRE
ROADWAY
HYSTERESIS
ADHESION

1204

ADHESION

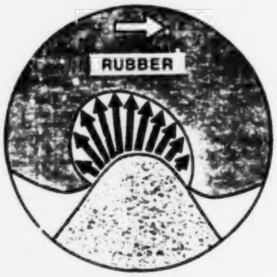
- Creep Speed
- Critical Speed
- Contamination
- Temperature Change
- Loading Pressure



1205

HYSTERESIS

- Speed
- Sliding Speed
- Dampening
- Pressure
- Contamination



1206

ACCIDENT STATISTICS

	1975	1978
Deaths	46,000	51,500
Disabling Injuries	1,800,000	2,000,000
Cost	$21.2 Billion	$34.3 Billion

1207

WET WEATHER ACCIDENTS

- Surface Wet Time
- Monthly Wet Time
- Seasonal Change

SESSION 13

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraphs 1301-1306

APPROACH: Note the following:

1. *Although we talk of skid resistance as friction supply less friction demand, what we usually measure is friction supply-not skid resistance.*
2. *The other part of the equation is friction demand-although we can control some part of this - i.e. roadway geometrics, we have little control over the rest.*
3. *This session deals with friction demand and we will necessarily look at those parts that we can control - i.e. highway geometrics.*

Lead into Participant Notebook -- Level of demand to be catered to, and area of greatest frictional demand.

SESSION GUIDE

SESSION: 13. VARIATION IN FRICTION DEMAND (NEEDS)

SESSION OBJECTIVES:

Friction demand varys depending upon the situation; for example, a different frictional level may be required at an intersection than on a tangent. The objectives of this section are to gain as thorough knowledge as possible on the relative demands and how they may vary depending upon speed, driving maneuvers such as weaving, the geometrics of the highway and environmental conditions.

REFERENCES: 1, 3, 11, 14, 15, 16, 17, 18, 19

CONTENT:

Friction Demand versus Friction Supply 13-2

Friction Demands of Traffic 13-3

Areas of Greatest Friction Demand 13-4

Frictional Requirements at Intersections 13-6

Frictional Requirements of Passing Vehicles 13-7

Frictional Requirements for Main Rural Highways 13-8

FRICTION DEMAND VERSUS FRICTION SUPPLY

Skid resistance can be thought of in terms of the margin of safety between the friction supply available and the friction demand generated at any particular time and for a particular driving maneuver.

Discuss friction demand versus friction supply using viewgraphs 1401- factors influencing friction demand, 1402 friction supply, and 1403 available friction and driver demand.

Thus the basic skid resistance equation is: Skid Resistance Friction Supply minus Friction Demand.

It should be emphasised that in normal usage skid resistance is equated to friction supply only. Sub-friction demand is also a major element of the skid relationship.

Table 13-1, which follows, lists the major factors that affect the skid equation.

FRICTION DEMAND	FRICTION SUPPLY
SPEED	SPEED
ACCELERATION AND BRAKING	TIRE
VEHICLE CHARACTERISTICS	PAVEMENT SURFACE
	Microtexture
WEATHER RELATED	Macrotexture
Wind	Drainage
Spray	Cross Slope
Sight	
	WEATHER RELATED
PAVEMENT GEOMETRICS	Rainfall
Curvature	Temperature
Superelevation	Cyclic Effects
Tracking	Seasonal

It is important to realize that certain factors by affecting both demand and supply can have a very great influence on skid resistance. Obvious examples are speed, which affects both friction demand and friction supply, and weather and environment related factors, particularly rainfall.

In the highway field, engineers are usually more concerned with friction supply since this is the part that can be directly influenced by pavement surface properties. Most of the remaining sessions in the course deal with measurements and design to increase friction supply. The remainder of this session is concerned with friction demand, which is just as important to skid resistance, but is not directly influenced by pavement properties, except geometrics.

FRICTION DEMANDS OF TRAFFIC

For a vehicle to follow a prescribed or desired course the tires must be capable of developing definite friction factors. These factors differ, and vary with speed, direction, vehicle, tire type, and, most importantly, with the maneuvers that drivers impose on their vehicles (changes in direction and rate of acceleration). Only rarely does the vehicle as such set the limits. One example of this is a truck ascending a steep grade.(1)

Rising mean traffic speeds and increasing traffic volumes on many highways have resulted in an ever increasing potential for wet pavement skidding accident occurrence. As speeds increase, friction demands increase but due to the nature of adhesion and hysteresis the actual tire-pavement friction available decreases.

The large dependence of available friction upon speed arises from the fact that on wet pavements the tire-pavement contact area is determined by the efficiency with which the tire can expel water from that area. Water viscosity and other effects cause this efficiency to degrade at higher speeds - consequently the tire is unable to maintain a dry contact area. The determination of tire-pavement frictional levels is highly dependent upon specific site considerations including the environment, traffic operational characteristics, and, most importantly, roadway geometry that determines vehicular maneuvers.(14)

AREAS OF GREATEST FRICTIONAL DEMAND

Research reports have shown that different accident rates can be attributed to different vehicle maneuver situations. (3, 11, 15, 16) A review of all NCHRP Reports revealed that intersections and curves are highway sites of highest accident involvement.

This is an important concept since the demand is so different between intersections maneuvers, curves, tangents, etc.

A skidding accident occurs when the maximum force which can be transmitted at the tire-pavement interface is exceeded.

In normal driving the greatest demand on friction is associated with geometric and control features. Although little data is available on the open-section acceleration behavior of drivers, such data as exist indicates that the distribution and magnitude of braking and cornering forces on an open section is much lower (i.e. heavy demand occurs with much lower frequency) than at sites whose roadway geometry requires a maneuver. In addition the frequency of accidents is substantially higher at maneuver sites than on tangent sections.

Use viewgraph 1404, skid numbers and accidents for four site categories.

While little has been published on the topic, there does appear to be a strong relationship between the frequency of skidding accidents and geometric elements. Although some of the information may now be dated it was reported at the 1958 International Skid Prevention Conference in Virginia that, compared to tangent sections, the skidding accident rate is 80 times greater on traffic circles, 48 times greater on curves with a radius less than 500 feet, from 3.8 to 13 times greater on grades, and 7.3 times greater at intersections. Despite the fact that most of the highway system consists of tangent sections, only 2.3 percent of skidding accidents occurred on tangent sections. (17)

Interesting statistics that should be called to participants attention-skidding accident rate 80 times greater on traffic circles than on tangent, 48 times greater on curves with radii less than 500 feet, 3.8-13 times greater on grades...etc.

Mahone and Runkle (18) conducted a study to provide the State of Virginia with information to determine the wet fricion levels needed for various traffic conditions on it's interstate system. The study sites were separated into four categories.

- Open roadway (level and tangent areas not at interchanges),
- Non-open roadway (vertical or horizontal curves or both not at interchanges),

- Open interchanges (level and tangent areas at interchanges), and

- Non-open interchanges (vertical or horizontal curves or both at interchanges).

Sight distance was considered of prime importance. Areas with gentle horizontal or vertical curves that afforded good sight distance were classified as open roadway.

The percentage of wet-pavement accidents was selected as the factor for analysis for two reasons. First, it was the only meaningful wet-accident figure easily obtainable, inasmuch as wet-accident rates were almost impossible to compute. Second, they hoped by selecting this factor the effect of traffic volume would be reduced. A basic assumption made in the analysis was that the amount of time the pavement was wet was considered to be essentially equal for all sections tested.

Several conclusions derived from the study were:

- The percentage of wet accidents decreased as the predicted available friction increased.

- If traffic volume were a factor at all, it appeared that on the average, the percentage of wet accidents was lower with increased traffic volumes.

- There was little difference in the percent of wet accidents for the four categories of roadway. However, there did seem to be some tendency toward increased accidents with increasing complexity of the roadway. The order of complexity in this case would be open roadway, non-open roadway and open interchange about equal, and then non-open interchange.

Mahone and Runkle point out that their results are averages and to apply them to a specific roadway situation as a general remedy for areas having a high percentage of wet accidents would not always be appropriate without considering factors such as the total wet-accident history.

FRICTIONAL REQUIREMENTS AT INTERSECTIONS

Wet-pavement skidding accidents occur most frequently at intersections. A pavement can be considered deficient in skid resistance only in relation to the skid demand of traffic upon it. Skidding can occur on a dry pavement when one attempts a sufficiently violent maneuver. Such demands can arise in an emergency or as a consequence of extremely poor driving, but the resulting skids should not be contributed to a deficient pavement. It is only when skidding occurs as a consequence of maneuvers that are within the range of normal demands (acceleration, braking, and cornering by a majority of drivers under normal traffic conditions) or intermediate demand (last-minute brake or steering corrections caused by inattention, misjudgment, or unusual incidents) that the pavement skid resistance should be considered inadequate. Realistic skid-resistance requirements are those that will accommodate all normal demands and a great majority of intermediate demands for the prevailing conditions of the site (17). Data gathered in one study indicated that 99 percent of the observed drivers were in normal or intermediate design categories.

Discuss why the skid requirements are greater at intersections.

Use viewgraph 1405, skid resistance requirments at intersections.

Friction demand at intersections varies due to a number of factors. By using a series of tape switches researchers at the Franklin Institute were able to measure friction demand at twelve intersections and determine tentative skid resistance requirements.

A tapeswitch is a vinyl-clad flat, flexible, pressure-sensitive, electrical strip switch. It is 3/4 inch (20 mm) wide, 3/8 inch (10 mm) thick, and can be cut to any length and fitted with a connecting lead. A series of such detectors, together with the appropriate electronics and recording equipment, can determine the time-position signature of a vehicle over some distance from which data acceleration values can be computed.

The researchers point out that the recommended guidelines are very tentative because they were based on extremely limited field data. These guidelines (summarized in Table 13-2) cannot be applied universally but should be evaluated and modified by further field studies.

TABLE 13-2

TENTATIVE GENERAL SKID RESISTANCE REQUIREMENTS AT INTERSECTIONS(17)

Design or Traffic Speed (mph)	L Point* (Ft.)	Relative Skid Resistance Needed
Below 40	330	0.89
40 to 55	415	1.00
Above 55	480	1.22

* The L point is the distance from the stop point at which skid resistance requirements apply.

FRICTIONAL REQUIREMENTS OF PASSING VEHICLES

Passing maneuvers probably account for the highest frequency of critical tire pavement friction demands encountered on rural two-lane highways. Not only are passing maneuvers performed at relatively high speeds, but they may also involve critical combinations of cornering and forward acceleration. In addition, passing vehicle maneuvers are generally performed adverse to the pavement cross slope.

Discuss the information in this section in conjunction with viewgraph 1406.

K. D. Hankings (11) reported on a study conducted in Texas, that approximately 40 percent of the vehicles involved in wet-weather accidents were, at the time of the accident, in a turning maneuver, about 33 percent were on horizontal curves, and 7.1 percent were passing.

A study was performed at the Texas Transportation Institute concerning the frictional requirements of passing vehicles.(19) Although no specific recommendations could be offered from the study, the results are summarized in Table 13-3.

TABLE 13-3

RELATIVE SKID RESISTANCE
REQUIREMENTS FOR PASSING VEHICLES

Speed (mph)	Relative Skid Resistance Requirements (Based on Measurement at 40 mph)
40	1.00
55	1.13
80	1.52

In the passing maneuver the friction requirement is greater for the initial maneuver than for the return maneuver.

FRICTIONAL REQUIREMENTS FOR MAIN RURAL HIGHWAYS

Kummer and Meyer performed a landmark study to determine frictional requirements for main rural highways.(3) In that study the problem of defining minimum skid resistance requirements was discussed in detail after establishing friction factors based on traffic needs. The standardized method accepted to measure skid resistance is specified in ASTM E-274, which requires measurement of pavement friction with a locked wheel equipped with a standardized tire.

Because locked-wheel pavement skid resistance measurements vary significantly with speed, and since skid measurements are a relative measure used for standardization, it is necessary to specify the speed at which the measurements are made. ASTM method E-274 requires 40 mph as the test speed.

For main rural highways, Kummer and Meyer (3) derived minimum tentative interim skid resistance requirements which showed that the skid resistance required at 70 mph was 40 percent greater than the skid resistance required at 40 mph.

It should be emphasized that the values given by Kummer and Meyer are recommendations and not standards. Various jurisdictions have adopted or prescribed minimum skid resistance values based on their own considerations. These considerations have included intuition and experience. Sometimes they include provisions for higher values at specified locations. The majority of standards and guidelines used have agreed with the recommendations of Kummer and Meyer (3).

1301

FACTORS INFLUENCING FRICTION DEMAND

- Speed
- Curvature
- Superelevation
- Tracking
- Wind
- Acceleration and Braking

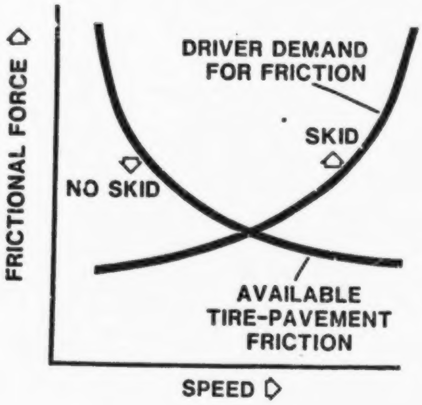
1302

FRICTION SUPPLY

- Weather
- Surface
  - Micro-texture
  - Macro-texture
- Drainage
- Cross Slope
- Tire
- Speed

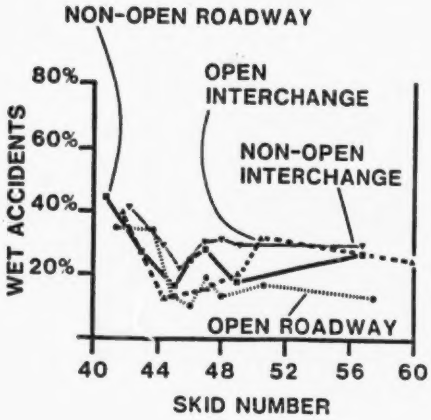
1303

AVAILABLE FRICTION AND DRIVER DEMAND



1304

SKID NUMBERS AND ACCIDENTS FOR FOUR SITE CATEGORIES



1305

GENERAL SKID RESISTANCE REQUIREMENTS AT INTERSECTIONS

Design or Traffic Speed (mph)	Distance from Stop Point	Requires Skid Resistance (SN)
Below 40	330	0.89
40 - 55	415	1.00
Above 55	480	1.22

1306

INTERIM SKID RESISTANCE REQUIREMENTS FOR PASSING VEHICLES

Speed (mph)	Relative Skid Number Requirement Based at 40 Miles Per Hour
40	1.00
55	1.13
80	1.52

SESSION 21

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraphs 2101-2107

APPROACH: This session covers the systems approach to Wet Pavement Accident Reduction, and one input to this systematic method, that is, Skid Tests.

Give background of a systems approach using V 2101 and how this session is central to the whole course - for example, V 2101 shows all the various inputs to a Wet Pavement Accident Reduction Program, and the outputs in terms of better methods for parent design and remedial treatment.

Lead into the Skid Test Program as one input, then revert to discussion of the overall program, based on one version given in Viewgraph 2105.

End session with discussion of the goals and objectives of the FHWA Wet Pavement Accident Reduction Program (use latest version: FHWA T.A. 5040.17 of December 23, 1980, Skid Accident Reduction Program).

EMPHASIS

1. *Systems approach to accident reduction*
2. *Skid surveys are just one input to the system.*
3. *The Wet Pavement Accident Reduction Program is the core of the course, and the whole course is devoted to looking at the inputs, outputs and variables involved.*

SESSION GUIDE

SESSION: 21. SKID RESISTANCE MEASUREMENTS AND THE WET PAVEMENT ACCIDENT REDUCTION PROGRAM

SESSION OBJECTIVES:

At the completion of this session course participants will understand skid resistance measurement objectives and how they relate to establishment of a wet pavement accident reduction program.

REFERENCES: 1, 20, 21, 22

CONTENT:

Introduction	21-2
Objectives of a Skid Test Program	21-2
Wet Pavement Accident Reduction Program	21-10
FHWA Wet Pavement Accident Reduction Program	21-15
National Survey of Skid Testing Equipment and Activities	21-19

INTRODUCTION

Federal law requires that the states maintain the highways that were constructed with federal-aid funds. The National Highway Safety Act of 1966 specifies that adequate skid resistance must be maintained, and the term "maintain" includes the correction of excessive slipperiness. According to the provisions of the Safety Act, this applies, however, not only to federal-aid highways, but to all highways and streets, including those under the jurisdiction of and constructed by local governments, even though no federal or state funds were used in their construction. V 2101

The Highway Safety Program Manual requires periodic surveys for the purpose of determining the prevailing skid resistance. Present requirements are not specific enough to serve as guides for what should be done, how, where, and when. Therefore, it is necessary for each individual jurisdiction to develop and conduct a skid survey program and select the means and methods for implementing it.

In many cases, skid resistance surveys can also serve functions other than those required by the maintenance mandate.

OBJECTIVES OF A SKID TEST PROGRAM

A basic objective of any skid resistance survey is to identify pavement sections that require rehabilitative action. Suspected sections can be identified from accident records: any location that shows an abnormal number of wet-weather accidents is a candidate for inclusion in a survey, as are sections and locations that are considered slippery by other means including citizen reports. V 2102

The next step is to include sections that are suspected of requiring corrective measures in the near future. Such sections are more difficult to identify, but departmental employees frequently have a feel for the rate at which skid resistance deteriorates and, therefore, can identify such sections.

If the rate at which skid resistance deteriorates is known or can be estimated, the frequency with which skid measurements should be made can be estimated. Generally, skid resistance drops rather rapidly with exposure to traffic immediately after construction and eventually

Predictions of skid resistance extremely difficult to estimate.

levels out at some near-equilibrium value. Therefore, one might be inclined to measure each section fairly often in the beginning and less frequently thereafter. However, this is necessary only if there is reason to assume that the skid resistance may drop below an acceptable level. On some pavements this never happens, or may do so after pavement rehabilitation needs are identified by other criteria; hence, too frequent measurement is not warranted at any time during pavement life.

There is not sufficient information available to adequately predict rate of skid resistance loss or the lowest value it will have. There are too many variables: traffic volume and composition, maneuvers, climate, weather, winter driving aids, snow and ice removal, contamination, and surface characteristic variables.

Gradual accumulation of life histories of the important pavement types within a selected jurisdiction through systematic, periodic surveys eventually permits predictions of the rate of skid resistance loss. Such data will also permit validation of accelerated laboratory tests on polishing characteristics. Systematic surveys will provide an inventory of data from which knowledge about long-range skid resistance performance of aggregates and pavements under a variety of conditions can be deduced.

Skid surveys are best planned by individual departments depending on their own circumstances

Thus, each highway department must plan a survey program that best serves its specific needs while furnishing the data required for consideration in scheduling resurfacing activities. Such programs are, of course, limited by the availability of measuring equipment and personnel. Because trailer-type testers can travel almost equally fast whether they are measuring skid resistance or not, proper routing becomes important and has a significant influence on unit measurement costs.

Frequency of surveys

For estimating purposes, one may assume that, on the average, Interstate and primary highways should be tested every one or two years, whereas other roads may be tested less frequently. Critical sections or locations (critical in the sense that they may cause serious increases in wet-weather accident rates or because they are near or can be expected to approach selected minimum slid resistance levels rapidly) may require more frequent measurement. In such cases, skid resistance should be checked at intervals of usually not more than 500,000 vehicle passes per lane.

If, tests are scheduled not just for comparison with recommended or mandated values, but to obtain performance data and histories of specific sections or pavement types, measurements at 40 mph should also be made. Otherwise, comparisons between different sections, type of construction, etc., are not possible, except in those cases in which the test methods are identical. When for this or other reasons several tests at the same site are to be made, it is essential that they be made one after the other. It is still not possible to reliably correct skid resistance measurement for temperature and for effects that may change the actual skid resistance over shorter or longer periods of time.

Any single measurement, of course, is subject to these "error" sources. This can become important when comparisons with a mandated minimum skid resistance value are to be made and the difference between mandated and measured values are small. This also applies when the survey data are being used to accumulate a history of specific sections or pavement types over several years.

Climate and environmental variables affecting skid surveys.

Ideally, surveys are best planned as concentrated efforts during late summer and early fall. Every winter, depending on geographical location and other factors, some recovery of the skid resistance of almost all pavements takes place. By late summer the winter effects have been obliterated, and the skid resistance of a particular pavement is probably at its lowest for the year.

Furthermore, almost everywhere in the United States the period of late summer-early fall (mid-July to mid-October) is one of infrequent rainfall and relatively stable temperatures. By scheduling the major part of the skid resistance tests during this part of the year, temperature and rain effects on the collected data are minimized. As experience is accumulated individually and collectively it will be possible to correct the skid number data for such effects.

Where the same pavement types or locations are to be compared from year to year, it will be advantageous to program the survey tests so that the same pavements or locations are tested not only during the same month, but also at the same time of the day or night in consecutive years. Tests are best scheduled for nighttime because traffic interference is at a minimum and temperatures are more stable than during the daylight hours. The presence or absence of solar radiation can have a significant effect on the effective test temperature and radiation effects are also much smaller during the night hours.

Pavements do not necessarily have uniform skid resistance, either transversely or horizontally. For comparison tests, suitable averaging techniques can reduce these effects to acceptable levels. When accumulating life histories of pavements or locations, the problem is not as easily solved. Every effort should be made to ensure that the same pavement location is tested every year.

Locational variables are of prime importance

The location of the test site longitudinally along the road is not critical if the pavement project was uniform to begin with and the traffic characteristics are such that wear and polishing may be considered as uniform. When this is not the case, mileposts or landmarks must be used to ensure that successive measurements are comparable.

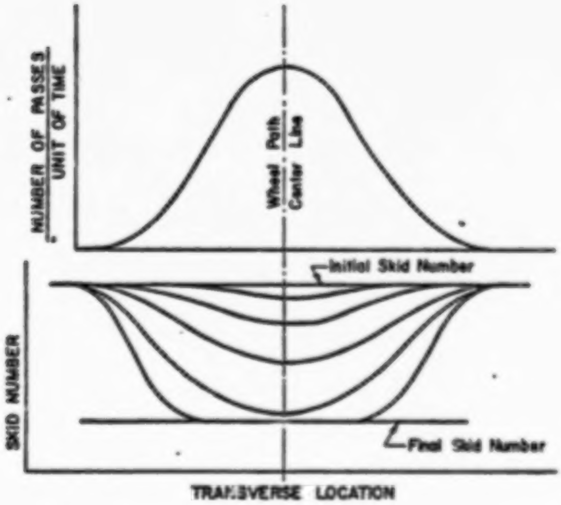
Lateral positioning of the tester during measurement is, however, extremely important, especially during the service life of the pavement. Considerable transverse differences in skid resistance can exist, particularly on roads on which traffic is strongly channeled. When the surface is new this is no problem. When it is old the polished part of the wheel path has widened sufficiently to make proper tracking less difficult. Figure 21-1 illustrates why skid resistance on pavements with longer service lives frequently show the largest scatter of data points prior to reaching the equilibrium value of skid resistance.

Data Acquisition

During individual tests the minimal data to be recorded are those specified in ASTM E 274 or an equivalent method. To obtain maximum benefit from surveys it may be advantageous to have additional data and information.

FIGURE 21-1

IDEALIZED CHANGE OF TRANSVERSE
SKID RESISTANCE
PROFILE OF A WHEEL PATH WITH TIME. (1)

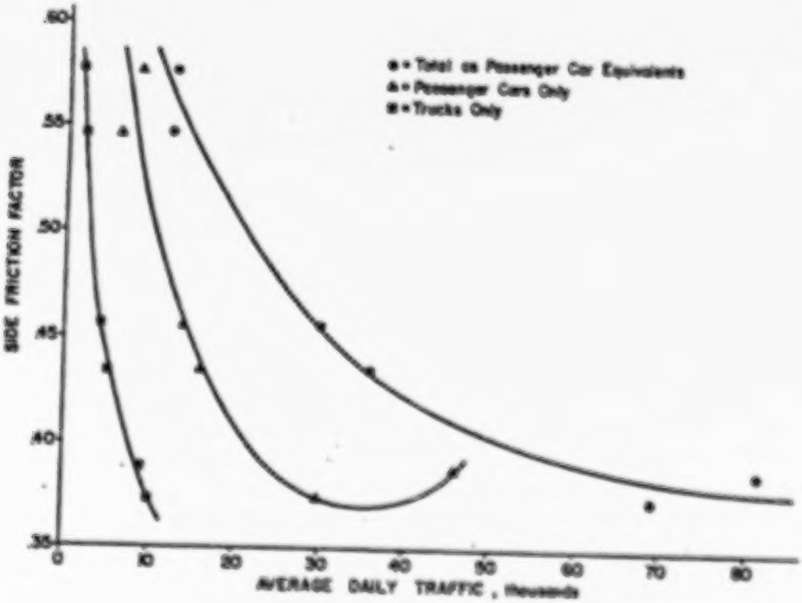

NUMBER OF PASSES / UNIT OF TIME
Wheel Path Center Line
Initial Skid Number
SKID NUMBER
Final Skid Number
TRANSVERSE LOCATION

For instance, there is some evidence that average daily traffic is not sufficient for defining traffic wear. There are indications that the number of commercial vehicles per day correlates better with pavement polishing than does the total number of vehicles. If total passenger car equivalents are plotted it appears as if a further increase in traffic density would not lower the skid resistance significantly. Whether Figure 21-2 can be generalized or not is unknown at this time. For this reason it is desirable to obtain information not only about total vehicle passes, but also about traffic composition.

Information should be obtained about stud use, nearby construction, or other activities that may have taken place just prior to a survey that may cause contamination of the surface. Weather and winter-maintenance records should be available along with the test logs. This information is necessary so that the reasons for abnormal changes in skid resistance can be determined.

FIGURE 21-2

SKID RESISTANCE VERSUS AVERAGE DAILY TRAFFIC



V 2103

Importance of collecting all subsidiary data

Obviously, all available information on the pavement, its design and construction, the source and mineralogy of the aggregate, etc., must be available if the survey results are to yield general information about the relation of these variables to the equilibrium skid resistance under prevailing traffic and other conditions. Only when this information is available can surveys produce the store of knowledge on which future improvements can be based.

Individual tests should be supported, to the extent practical, by secondary data. Temperature, as an important effect on measured skid resistance, should be recorded. At a minimum, air temperature should be measured. It is only indirectly related to the temperatures at the tire-pavement interface, but is useful when examining large deviations from expected skid resistance values. Wet-pavement temperature is more representative of the several governing temperatures and can be used to correct skid numbers for deviations from a selected base-line temperature (usually 70 degrees F). However, it should be noted that, even for a given test tire, somewhat different corrections apply to different pavement types.

To obtain wet-pavement temperature it has been necessary for the test crew to leave the vehicle and apply a suitable temperature sensor to the pavement. For this reason it was scarcely possible to make such measurements for every skid test, or even on every project. Cost and safety considerations, with due regard for the probable error, if only occasional pavement temperatures were taken decided how often and where such measurements were to be made. New infrared thermometers now available can measure pavement temperatures during testing.

Ideally, for every pavement, skid resistance should be known not at just one speed, but as a function of speed over the range of speeds at which traffic moves. This ideal can be approached by measurement at two speeds, suitably spaced. This requires, in many cases, traversing the same highway section twice. If a project is long and uniform, high- and low-speed measurements can be alternated.

The Skid Number - Speed Gradient (G) is a ratio of the change in skid number resulting from change in speed. Thus:

Emphasize speed gradient

$$G_{A-B} = \frac{SN_A - SN_B}{B - A}$$

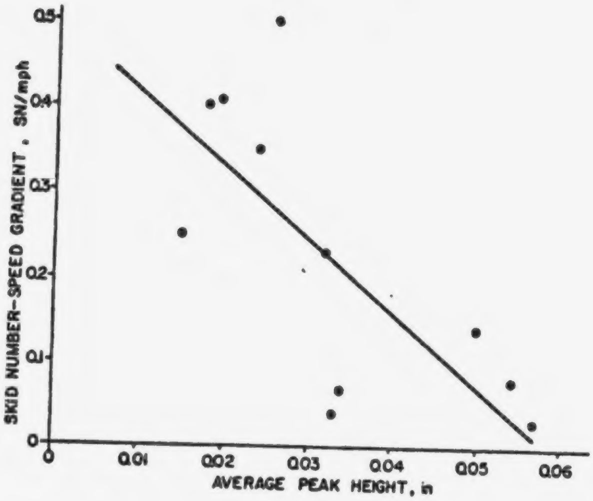
where A and B are the test speeds at which the skid number is determined.

Instead of making all skid resistance measurements at two speeds, one may supplement single-speed measurements with texture measurements. Because texture is related to the change of the skid resistance with speed, it is possible to infer the skid number at one speed from the measured skid number at another speed as illustrated in Figure 21-3.

Photographs, preferably sterephotographs, both in and outside the wheel track, can be taken at the same time and will provide additional documentation that will be helpful when interpreting the results of several years. Such photographs should be made with the camera mounted on a box with internal lighting to reduce apparent differences due to changes in lighting.

FIGURE 21-3

SKID NUMBER-SPEED GRADIENT
VERSUS
AVERAGE PEAK HEIGHT



When pavements are grooved, groove depth should be measured, and if the pavement is permeable, permeability measurements should be made. In both cases, standard skid resistance measurements do not tell the full story because such pavements are less dangerous than their skid resistance would indicate. Measurements of hydroplaning potential would be necessary to properly rank them with respect to high-speed accidents, but as yet no practical method for making such measurements as a matter of routine has been developed.

Pavement roughness, if not so severe as to be objectionable as such, does not influence the trailer skid resistance measurements, but it can affect the behavior of vehicles during locked-wheel stops. Hence, it is desirable to make any roughness measurements that are scheduled at the locations at which skid resistance is being measured during the periodic surveys.

Data Evaluation

One problem with surveys is that they generate a large mass of data that must be analyzed and related to location, pavement design, weather, etc., and to the data from earlier and future surveys. Sections needing rehabilitative measures must be identified. This work should be done promptly so that abnormal data can be checked and their causes determined before large changes have taken place or winter makes it impossible to determine the cause.

Histories should be compiled from consecutive surveys for pavements embodying new design features. This is to provide base lines for future design changes or different volumes and mixes of traffic, and to develop a basis for long-range planning of maintenance activities.

The value of routine surveys can be greatly enhanced by proper evaluation and presentation of the results. Computerized data processing can be very useful when several hundred or thousand individual test sections need to be surveyed. The collated data should, of course, be made available or readily accessible to all offices and individuals concerned; that is, to maintenance, materials, pavement design, geology, traffic engineering, etc.

WET PAVEMENT ACCIDENT REDUCTION PROGRAM

With the buildup of knowledge in the field of pavement skid resistance, it has become clear that a well conceived inventory program is needed.

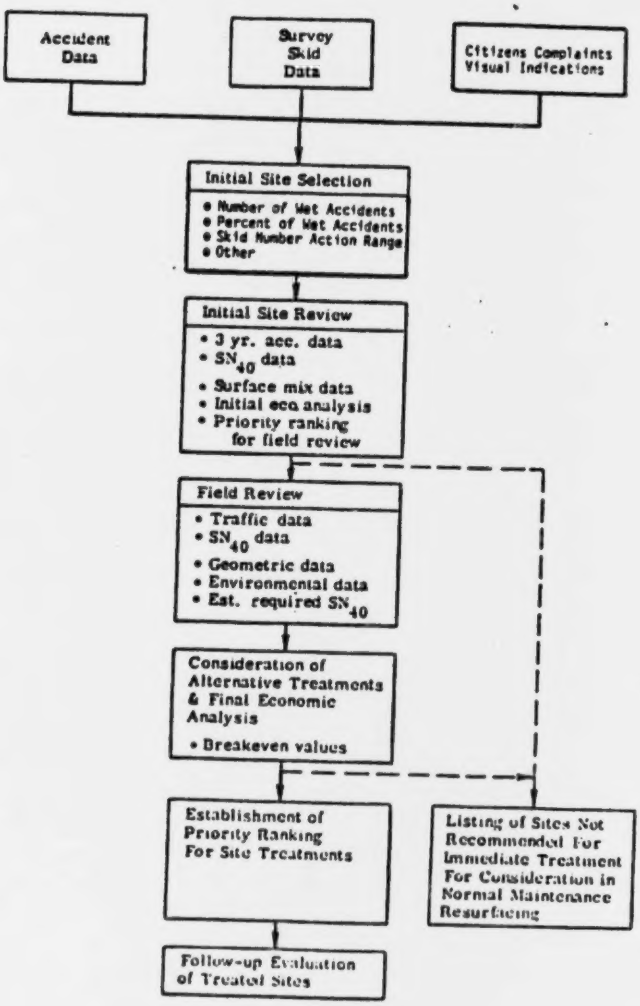
Outline of Program
V 2104

The outline of such a program includes first: a decision about which roadway systems are to be included in the inventory. The program that will be outlined includes the Interstate, Arterial and Primary Roadway Systems. Potential high wet pavement accident locations on the secondary road system are evaluated when brought to the attention of those responsible for the program, however, the procedures described herein for locating possible high wet pavement accident sites are not directly applicable to the secondary system.

A generalized flow diagram of a wet pavement accident reduction program is shown in Figure 21-4.

FIGURE 21-4

WET PAVEMENT ACCIDENT REDUCTION PROGRAM


Accident Data
Survey Skid Data
Citizens Complaints Visual Indications
Initial Site Selection
• Number of Wet Accidents
• Percent of Wet Accidents
• Skid Number Action Range
• Other
Initial Site Review
• 3 yr. acc. data
• SN40 data
• Surface mix data
• Initial eco. analysis
• Priority ranking for field review
Field Review
• Traffic data
• SN40 data
• Geometric data
• Environmental data
• Est. required SN40
Consideration of Alternative Treatments & Final Economic Analysis
• Breakeven values
Establishment of Priority Ranking For Site Treatments
Listing of Sites Not Recommended For Immediate Treatment For Consideration in Normal Maintenance Resurfacing
Follow-up Evaluation of Treated Sites

More detailed Program V 2105

Give reasons for consideration of each item in the flow chart

An evaluation of the diagram highlights the importance attached to the use of accident data. While it obviously is important to identify and consider improvements to potentially dangerous sites, i.e., sites having low skid resistance, it is more important to identify and correct sites already characterized by a high frequency and proportion of wet accidents.

Accident data utilized in the program may be obtained in most states from automated accident files. Table 21-1 summarizes the type of data that is contained in such files.

TABLE 21-1

DATA ITEMS CONTAINED IN EACH ACCIDENT RECORD

Item	Item
Report Number	Light
Month	Weather
Date	Type of Collision
Year	Fixed Object
Hour	Skidding
District	Zone of Impact
County	Major Factor
Cities & Towns over 3,500	Severity
Towns Under 3,500	Number Killed
Route	Number Injured
Section Number	Number Vehicles Involved
Milepoint	Amount of Property Damage
Surface Type	Card Control
Surface Width	Type of Vehicle (per vehicle)
Kind of Highway	Speed (per vehicle)
Speed Limits	Residence of Driver (per vehicle)
Intersection Type	Vehicle Maneuver (per vehicle)
Intersection Route Number	Placement (per vehicle)
Accident Location	Driver and Pedestrian Action (per vehicle)
Alignment	Condition of Individual (per vehicle)
Surface Condition	Vehicle Condition (per vehicle)
Defective Road Conditions	Visibility Conditions
Traffic Control	

V 2106

Data considered to be of primary importance are locational data, placement data indicating direction of travel, surface condition (dry, wet, snowy, icy, etc.), number killed, number injured, and property damage. Other items are obviously of importance at times, but the above items are always considered.

In developing a survey skid testing program it is important to have a correlation between the skid test vehicles if more than one is used so that the data may be interchanged.

The number of tests per lane mile may vary however three is an often used number. If funds and equipment are available every lane should be tested.

Procedures for the collection and computer storage of survey skid data, as well as the utilization of the data considering variabilities present in testing have to be worked out. Data items that should be contained in each skid test record are listed in Table 21-2.

TABLE 21-2

DATA ITEMS CONTAINED IN EACH SURVEY SKID TEST RECORD

V 2107

ITEM

District
Residency
County
Route Number
City/Town/County
Test Vehicle
Test Wheel
Calibration
Operators
Date of Test
Time of Test

ITEM

Weather Condition
Air Temperature
Surface Temperature
Tread Depth
Direction
Lane
Data Type
Milepoint
Speed
Skid Number

Potentially high wet accident sites may be selected on the basis of 0.5 mile segments, incremented by 0.1 mile lengths. For example, the initial segment on a route would be from milepost 0 to milepost 0.5, the second segment from 0.1 to 0.6, and the third from 0.2 to 0.7. A site is selected as a possible high wet pavement accident site when three or more wet accidents occur in the 0.5 mile section, provided the wet accidents account for at least 30 percent of the combined total of wet and dry pavement accidents.

The site selection process just described should be performed each year by an automated review of the latest year's detailed accident computer file. The output provided from this process is illustrated in Figure 21-5. Notice that for each site selected locational information, as well as the number of fatal, injury, and property damage accidents, the number of fatalities, number of injuries, and amount of property damage for both wet and dry pavement accidents is summarized.

FIGURE 21-5

EXAMPLE OF COMPUTER OUTPUT FOR SELECTION OF HIGH WET PAVEMENT ACCCIDENT SITES. (20)

DI	CO	CTY	ROUT	MILEPOINT FROM	MILEPOINT TO	WET ACCIDENTS FAT. ACCD	NO. KILL,	INJ. ACCD	NO. INJ	P/D ACCD	AMOUNT P/D	TOT ACCD	DRY ACCIDENTS FAT. ACCD	NO. KILL	INJ. ACCD	NO. INJ	P/D ACCD	AMOUNT P/D	TOT ACCD	PCT WET
5	01		0013	.1	.5					3	1100	3								100 00
5	01		0013	3.7	4.1					5	4300	5			1	1	1	700	2	71.43
5	01		0013	4.0	4.4					4	3600	4			1	1	2	4000	3	57.14
5	01		0013	7.5	7.9			3	4	9	14700	12					3	3500	3	80.00
5	01		0013	7.7	8.1			3	4	9	14700	12			1	1	2	1900	3	90.00
5	01		0013	7.8	8.2			2	2	5	8400	7			1	1	2	1900	3	70.00
5	01		0013	13.2	13.6			1	2	3	3400	4					1	100	1	80.00

Annually, as survey skid testing is completed within a highway district the detailed skid output should be reviewed, and SN values below a preselected minimum brought to the attention of the proper authorities.

FHWA WET PAVEMENT ACCIDENT REDUCTION PROGRAM (21)

The FHWA Wet Pavement Accident Reduction Program is a part of the overall highway safety improvement program. For a more in-depth study of the overall safety program, reference can be made to the three National Highway Institute courses entitled:

- Highway Safety Improvement Program
- Highway Safety Evaluation
- Highway Safety Engineering Studies

Reference should also be made to FHWA Technical Advisory T5040.17 of December 23, 1980 for up to date guidance as a Skid Accident Reduction Program.

The purpose of the skid accident reduction program of the Federal Highway Administration is to reduce skidding accidents on wet roads through the application of a systematic plan for the identification and correction of sections of roads with high or potentially high skid accident incidence. This systematic plan should include at least three basic activities:

1. The evaluation of pavement design, construction, and maintenance to ensure that only pavements with good skid resistance characteristics are used in construction and resurfacing.
2. The detection of locations with a high incidence of wet pavement accidents by utilizing the State accident record system and local accident record system as applicable, and the development of priorities for correction of the locations.
3. The analysis of skid resistance for all roads with a speed limit of 40 mph (64 km/h) or greater, so that skid resistance can be given consideration in the development of priorities for resurfacing and maintenance programs.

BEST DOCUMENT AVAILABLE

General Elements

To carry out these activities, each State should develop a program reflecting its individual needs and conditions. This program should provide essential support data in three areas. These areas coincide with the three basic activities described previously.

1. Selected Sections - Measurements of skid resistance of selected test sections to determine the skid characteristics of typical design mixes. Sufficient numbers of measurements should be made to determine the level of pavement friction, wear rate, and speed gradient of the pavement under various traffic exposure.

2. Accidents - Measurements of skid resistance at locations of high wet weather accident experience (high wet/dry ratio, high wet accident rate, high numbers of accidents, etc.)

3. General Inventory - Measurements of skid resistance to develop a general skid inventory for all roads in the State with a speed limit of 40 mph (64 km/h) or greater. The inventory should be capable of producing the general status of skid resistance on all applicable roads in the State. This can be developed on a sample basis, but must contain sufficient accuracy to allow its use for planning purposes.

   The inventory should be maintained on a continuing basis.

General Considerations

It should be recognized that seasonal variation in frictional values may occur. This seasonal variation should be considered when using skid measurement data.

Basic Activities

1. Selected Sections

   A. Planning - Identify the major pavement wearing surfaces used in the existing highway systems.

Identify representative locations of the major pavement wearing surfaces.

Select representative test sites for each major surface which include major variables such as aggregate type, traffic exposure, age, etc.

B. Measurement - For test measurement procedures, refer to ASTM E 274.

Speed Gradient or some other valid means of indicating performance at high speeds, such as texture measurements, is necessary.

In addition to tests on selected sections - unproven or experimental surfaces should be measured frequently to obtain skid resistance performance information.

C. Analysis - the skid resistance performance of the various major pavement surfaces (based on results of the Selected Section tests) should be determined in terms of skid resistance versus cumulative traffic.

- The overall test result variation should be analyzed by establishing a regression line and by determining a standard error of estimate.

- The data should be analyzed for acceptable performance throughout the design life of the wearing surface.

  Surfaces exhibiting poor performance should be evaluated in greater detail to determine the effects of the major variables (aggregate, texture, traffic density, etc.).

- The findings will be used to provide surface types which have skid resistance qualities that will meet the anticipated traffic needs.

D. Continuation - The performance of the major pavement wearing surfaces should be monitored on a continuing basis.

2. Accidents

A. Planning - Accident records should be analyzed to find locations of high wet weather accidents based on high wet dry accident ratios, high wet accident rates, high numbers of accidents, etc.

B. Measurement - The length of a test section for a designated site should be representative of the pavement on which the accident(s) occurred.

Consideration should be given to speed gradient, surface texture information, or other valid indicator(s) of performance at high speeds where appropriate.

C. Analysis - Skid resistance measurement data, along with other pertinent data, should be used in an engineering analysis and evaluation to identify:

- the causative accident factors including those other than low skid resistance,
- possible corrective measures,
- the appropriate action,
- and priorities for implementation.

D. Continuation - A follow-up of corrective action(s) by continued monitoring to determine if reductions in wet weather skidding accidents or improvements in performance were obtained.

3. General Inventory

A. Planning - Criteria to consider in the selection of the roadway to be inventoried for skid resistance.

- The roadways should have a speed limit of 40 miles per hour (64 km/h) or greater.
- Separate the roadway system into classes or types according to skid resistance needs. This separation will depend largely on individual needs within each State. Examples of classes or types are - ADT, roadway use, road systems, etc.

- Geographical locations as affected by climate, terrain, and pavement aggregate should be considered in selecting samples of roadway test sections.

  A sample skid number survey should be conducted on the classes or types of roadways, where a reasonable level of sampling performed within a geographical area would be representative of the various classes or types chosen.

B. Measurement - For test procedures, refer to ASTM E 274.

For additional reference on sampling procedures, see NCHRP No. 151, 1974.

C. Analysis - The skid resistance distribution should be determined for the classes or types in the established geographical areas.

The distribution should be used as an input for developing priorities for further evaluation, testing, and appropriate action.

Skid resistance should be considered in establishing priorities for resurfacing or other rehabilitation priorities.

D. Continuation - Monitoring improved roadway systems should be based on information developed in previous phases, and enable the maintaining of an updated inventory data base.

NATIONAL SURVEY OF SKID TESTING EQUIPMENT AND ACTIVITIES

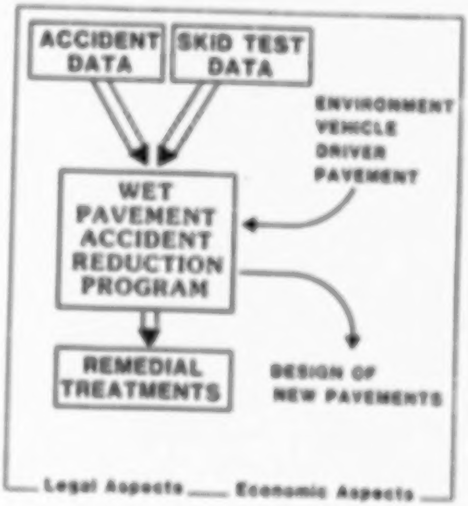
The Indiana State Highway Commission conducted a national survey of skid testing equipment and activities and published the results in July 1977 (22).

From that survey it was found that almost all states have a skid test inventory program. Some states skid test their entire road system every year. Others do this on a less frequent basis. It was found that most skid testing is done at the rate of one test per mile. Some states, however, run as many as five tests per mile. At least two states test on the basis of specific test sites selected in accordance with a predetermined criteria. A few states report testing all bridges and intersections. Most states store their skid test data in a computer for future use.

Several states report considerable special skid testing. Some of the testing is performed at the request of district and maintenance engineers. Other special testing is performed in support of research of accident prone areas and surfaces, special bituminous mixtures, aggregates, and many other studies that have a potential of improving safety and scientific knowledge.

The typical skid testing operation requires two men. In most instances these men also reduce data and perform repairs on their units.

2101

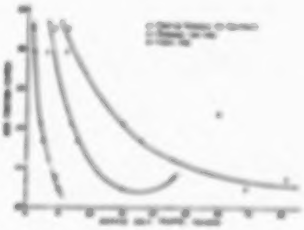

ACCIDENT DATA
SKID TEST DATA
ENVIRONMENT
VEHICLE
DRIVER
PAVEMENT
WET PAVEMENT ACCIDENT REDUCTION PROGRAM
REMEDIAL TREATMENTS
DESIGN OF NEW PAVEMENTS
Legal Aspects
Economic Aspects

2102

SKID TESTING CAN IDENTIFY:

- **Pavement Needing Immediate Remedy**
- **Pavement Needing Remedy in Near Future**

2103



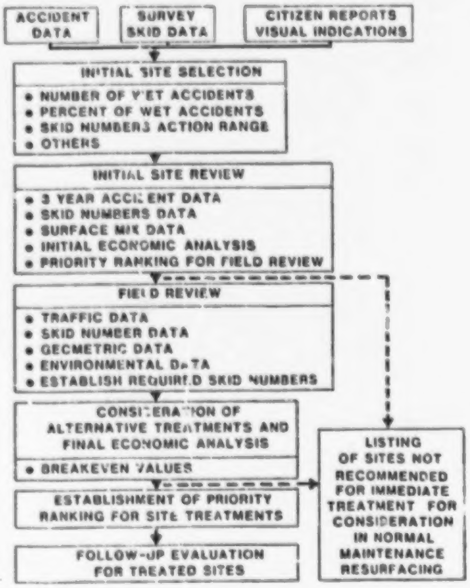
2104

WET PAVEMENT ACCIDENT REDUCTION PROGRAM

Accident Data ▷ **Survey Skid Data** ◁

Site Selection
▽
Site Review
▽
Field Review
▽
Consider Alternatives/ Economic Analysis
▽
Establish Priorities
▽
Follow - up

2105


ACCIDENT DATA
SURVEY SKID DATA
CITIZEN REPORTS VISUAL INDICATIONS
INITIAL SITE SELECTION
• NUMBER OF WET ACCIDENTS
• PERCENT OF WET ACCIDENTS
• SKID NUMBERS ACTION RANGE
• OTHERS
INITIAL SITE REVIEW
• 3 YEAR ACCIDENT DATA
• SKID NUMBERS DATA
• SURFACE MIX DATA
• INITIAL ECONOMIC ANALYSIS
• PRIORITY RANKING FOR FIELD REVIEW
FIELD REVIEW
• TRAFFIC DATA
• SKID NUMBER DATA
• GEOMETRIC DATA
• ENVIRONMENTAL DATA
• ESTABLISH REQUIRED SKID NUMBERS
CONSIDERATION OF ALTERNATIVE TREATMENTS AND FINAL ECONOMIC ANALYSIS
• BREAKEVEN VALUES
ESTABLISHMENT OF PRIORITY RANKING FOR SITE TREATMENTS
FOLLOW-UP EVALUATION FOR TREATED SITES
LISTING OF SITES NOT RECOMMENDED FOR IMMEDIATE TREATMENT FOR CONSIDERATION IN NORMAL MAINTENANCE RESURFACING

2106

ACCIDENT REPORT INFORMATION

- Date/Time
- Daylight/Darkness
- Weather
- Pavement Type
- Pavement Condition
- Location
- Vehicle Type
- Description of the Event
- Property Damage/Injuries/Fatalities
- Collision Diagram

2107

SKID TEST RECORD ITEMS

District
Route Number
Milepoint
Direction
Lane
City/Town/County
Test Vehicle
Test Wheel

Date/Time
Weather
Air Temp
Surface Temp
Operators
Data Type
Calibration
Skid Number

SESSION 22

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS Viewgraphs V 220-220

APPROACH: Accident Data is the second major input to Wet Pavement Accident Reduction Program.

Discuss the fact that accident reports are used by many people and therefore should be checked to see if they contain the data required to be useful in a skid context.

Case studies should be introduced at the appropriate point. Emphasize subjective aspects of panel rating.

Conclude with V 2209: Accident records serve many purposes, one of which is to identify High Accident Locations.

SESSION GUIDE

SESSION: 22. DETECTION OF SLIPPERY CONDITIONS - ACCIDENTS, CITIZEN REPORTS AND VISUAL INDICATIONS

SESSION OBJECTIVES:

At the end of this session, participants will be familiar with methods of detecting slippery conditions other than skid testing, including the investigation of accident data, citizen complaints, and visual indications.

REFERENCES: 3, 23, 24, 25, 26, 27, 28, 29, 30

CONTENT:

Collection and Use of Accident Data 22-2

Detection of Slippery Conditions - Accident Data 22-4

Accident Data and the Wet Pavement Accident Reduction Program 22-8

COLLECTION AND USE OF ACCIDENT DATA

The completeness, accuracy, and extent of accident causation data collected and stored by present accident record systems are unknown. Usually, those having the responsibility for collecting and recording accident data have other responsibilities at the scene of an accident. V 2201

Although it is not economically feasible and probably not possible to have teams perform detailed studies for each accident, it certainly would supply badly needed information and insight on the causes of accidents. Lacking such a comprehensive approach, in most cases, the responsibility of recording the accident information lies with the investigating officer.

Five basic purposes of traffic accident records are:

- To provide knowledge of traffic accidents as a cause of mortality and economic loss.
- To point out where, when, and to whom traffic accidents are a critical problem.
- To suggest preventive action to be taken.
- To measure the effect of accident prevention efforts.
- To determine negligence or fault.(23)

Good traffic accident records contribute to the traffic accident prevention efforts of agencies having responsibility to take corrective actions in a number of ways. These records include characteristics that:

- Identify categories of driver problems which are in need of corrective action by agencies responsible for driver license administration, education, enforcement, and administration of financial responsibility laws.
- Assist educators in the development of driver education programs and provide meaningful information for the general public on traffic accident causation and prevention.

- Point out high accident or hazardous locations for corrective action.
- Identify street and highway deficiencies and justify standards and general guidelines for roadway designs that assist in the elimination of traffic accidents.
- Define the scope of highway safety problems with which traffic police must deal, and provide guidelines for the development of selective enforcement procedures.
- Assist legislative bodies in the preparation of laws and ordinances, and government administrators in the formulation of administrative regulations.
- Identify areas in which further research is needed about drivers, vehicles, traffic control, and highway design.

In most states there is a legal requirement that accidents be reported to a specified state agency on a report form developed by that agency. This agency then becomes the repository for accident records and usually is regarded as a principal user of the data. It is absolutely necessary to have a data collection form that is both simple and concise. The information should be recorded for ease of inclusion into an accident data system that ought to be computerized. Due to the great magnitude of highway data it is no longer feasible to hand manipulate information. Most states now have standarized their data systems. Locational information usually is by district, county, residency, route and milepost or some variation of this format.

Note that accident records are used for a multitude of purposes other than input to a Wet Pavement Accident Reduction Program.

Among the generally common users of accident data are police, courts, legislators, transportation departments, motor vehicle departments, insurance firms, involved individuals and attorneys. In this course the emphasis is on the usage by transportation departments.

Users of Accident Report information V 2202

Pavement properties contribute one-half of the physical interface that determines vehicle control. The other half, of course, is the tire. For this reason an accident data system should be merged with a pavement data system. When an accident occurs, pavement data such as pavement type, age, types of materials, curvature and other geometric design features can be analyzed in conjunction with the accident data. An analysis of this information by experienced personnel can reveal the cause of accident. Enough experience has been gained over the years to predict the approximate degree of slipperiness of pavements given the accumulated traffic volumes, the type of finish incorporated into the pavement, and the materials included in the pavement mixes.

DETECTION OF SLIPPERY CONDITIONS - ACCIDENT DATA

The use of accident records to establish a data base to predict future accident occurrence is an accepted approach in the highway safety field.(24) The fact that a high incidence of accidents occur at some locations can be documented from the literature. As all are aware, there are numerous causes of accidents. Most often, accidents are the result of a number of contributing factors. One contributing factor is inadequate skid resistance as compared with the frictional demand to meet normal driving maneuvers. Some other factors that may lead to skidding accidents are:

- Tire-pavement friction interaction that is influenced by factors of instantaneous acceleration (abrupt speeding up or slowing down), *V 2203 and V 2204*
- Acceleration or deceleration,
- Centrifugal force,
- Steering angle,
- Tire type,
- Tread wear,
- Pavement surface texture,
- Driver behavior,
- Rain and visibility,
- Volume, density, and speed of the traffic stream,
- Traffic control and regulation. (25)

In order for accident data to be effectively used in detecting slippery pavements a systematic approach must be developed. Although no standard pattern or procedure for such an approach exists, at least four key elements are essential in terms of an effective anti-skid program:

- Accidents that result in more than a specified amount of damage should be reported;
- A location information system that is capable of pinpointing accidents accurately (which also requires some form of field reference system) should be established;
- Environmental information concerning each accident should be reported to permit identification of accidents caused by skidding;
- A storage and retrieval system that will provide quick and automatic notice of concentrations of skidding at highway locations or sections.

If these four elements are met, the foundation exists for skid restoration program that is based on accident experience. The state of the art is such that these requirements can be met; and, although not all states have reached this point, there are enough examples to prove the practicality of the idea.

The Federal Aid Highway Program Manual 8-2-3, Safety Improvement Program, transmittal 298, set forth the policy that each state shall develop and implement, on a continuing basis, a highway safety improvement program which has the overall objective of reducing the number and severity of accidents and decreasing the potential for accidents on all highways.(26)

This policy covers:

- A process for collecting and maintaining a record of accident, traffic, and highway data, including, for railroad-highway grade crossings, the characteristics of both highway and train traffic;

- A process for analyzing available data to identify highway locations, sections, and elements determined to be hazardous on the basis of accident experience or accident potential;
- A process for conducting engineering studies of hazardous locations, sections, and elements to develop highway safety improvement projects.
- A process for establishing priorities for implementing highway safety improvement projects.

To carry out this policy the following must be established:

- A field reference system for identifying the location of individual occurrences, such as reference posts, coordinates, etc.;
- A traffic records system with the ability to correlate collision data with vehicle, driver, and highway data including the ability to correlate accident experience with existing geometric features and traffic characteristics at specific locations. An ultimate objective of the system should be to identify causative factors of highway collisions;
- A procedure for identifying and reporting hazardous elements and locations based on accident analysis. This will involve analysis of actual accident experience at specific locations, analysis of accidents related to specific elements or geometric features throughout a route section, route system or area, and/or application of approved traffic forecasting procedures based on traffic characteristics.

V 2205

The progress of the states in complying with the demands of the FHWA directive has been mixed but generally satisfactory. Several factors go into a complete program of this nature beginning with a field reference system. Without such a system the problems of determining the highway location of accidents are greatly increased. Without good locational information the whole system breaks down. In this area much has been accomplished by the states. Most states have installed mileposts, or reference markers, but not necessarily on every mile of road. In general, states have installed mileposts on the Interstate system, and some have extended or will extend the system to all Federal-Aid primary routes.

A second factor is a records system to summarize data systematically and which can be used to correlate accidents with highway data. Every state has a records system but a comprehensive evaluation of these systems is not available. In 1967, the question was asked, "Do you utilize state accident information for the detection of slippery pavements?" Out of 37 answering the question, 19 said "yes" and 18 said "no" (3). Of 18 states responding to the question "Is accident information sufficiently detailed to establish the number of wet pavement accidents which are clearly due to skidding?" Only four indicated that the information was sufficient. This suggests that in 1967, the large majority of states believed the number of wet accidents due to skidding was not clearly known.

A third factor is the capability to identify hazardous features and locations based on accident analysis. About 80 percent of the states are currently able to use a method other than public comment or engineering judgment to identify hazardous locations. The most commonly used evaluation methods to identify hazardous locations are about equally divided among three approaches:

- The number of accidents,
- A combination of number of accidents and the accident rate (called the number-rate method),
- A statistical method that identifies a significantly high accident rate (the quality control method).

Although these three methods vary in the degree of sophistication, any one is superior to the "brush-fire" approach that is some times used.

Regardless of the case, the important point is that decisions are based on accident records, not on subjective notion that a particular section is slippery. The information may come from any of several sources including:

- Driver reports,
- Police reports,
- The sample data from a bi-level system,
- Reports of multidisciplinary teams.

The size of the sample is important because the number of cases will probably be small. Using the maximum number of reports is the best way to avoid missing specific locations that might be overlooked or bypassed in a sampling process.

Statistical problems with accident records.

Another factor that must be considered is the recognized idea of "regression toward the mean." If a location has a high accident experience for a given period of time, the chances are that in a following period the experience will be lower. This means a sufficiently long time period with a large enough exposure and significant number of accidents to be meaningful.

This question of meaningful or statistically significant figures leads directly to another aspect of accident records and their application to an anti-skid program: The use of accident records can be used as a measure of program effectiveness. The most commonly employed technique is a "before and after" comparison. This comprises making a comparison of wet weather accidents before and after skid rehabilitation efforts. Here again, certain cautions must be heeded. The before and after periods should be comparable in terms of time, weather, and traffic. This is particularly important when dealing with skidding accidents because comparing a rainy before period with a dry after period would distort the relative exposure conditions for wet pavements.

Discuss case studies.

Two studies of specific uses of an Accident Data Bank are given in Exhibit 2101 at the end of the session.

ACCIDENT DATA AND THE WET-PAVEMENT ACCIDENT REDUCTION PROGRAM

Current FHWA guidelines state in part that the purpose of the skid accident reduction program is to reduce skidding accidents on wet roads through the application of a systematic plan for the identification and correction of sections of roads with high or potentially high skid accident incidence. This systematic plan should include at least three basic activities:

- The evaluation of pavement design, construction, and maintenance to ensure that only pavements with good skid resistance characteristics are used in construction and resurfacing.
- The detection of locations with a high incidence of wet pavement accidents by utilizing the state accident record system and local accident record system as applicable, and the development of priorities for correction of the locations.
- The analysis of skid resistance for all roads with a speed limit of 40 mph (64 km/H) or greater, so that skid resistance can be given consideration in the development of priorities for resurfacing and maintenance programs.(27)

From the preceding discussion it is apparent that one of the prime ways of detecting slippery pavements, and especially slippery spots, is from accident data. However, to be able to effectively use such data a systematic plan must be in effect. With the magnitude of data now in existence the only feasible way of storing data is by computer. To make accident data more useful in detecting slippery areas, the accident data system should be designed as part of a highway data bank where it may be recalled separately or in conjunction with other automated systems. Virginia designed such a system where pavement data could be recalled simultaneously with skid data, accident data, and volume data along with the resident engineer's comments.(28)

To reiterate the foregoing points, for an accident data system to yield maximum benefits in the detection of slippery pavements, it would contain the following major features:

- A precise and comprehensive accident report filing system,
- Accurate locational information,
- A designated state agency charged with the responsibility of maintaining the records,

V 2206

- A record system designed to summarize data systematically and to correlate accidents with highway data,

- A system that indicates accident prone or potentially accident prone locations.

- Quick distribution of information to those responsible for corrective actions with probable causes of accidents and remedial actions suggested.

Detection of Slippery Conditions — Citizen Reports

Citizen reports are another method of detecting skid prone sites. This is a method that should not be overlooked because it occurs in most cases before the accident occurs. Closely related to citizen reports are news media reports. In many cases a citizen will voice his concern to the media.

In many cases, citizens do not know to whom they should report slippery conditions. Consequently, a public information and collection system can be very helpful to obtain citizen input. Such a system has the same goal as the accident data feedback system, and that is to get the information concerning the slippery condition to the proper authority.

More investigation is necessary in certain aspects of citizen reports by the highway authorities that with accident data. The average motorist is not trained in reporting highway conditions as is the accident investigator. Since the motorist is probably not familiar with milepost systems, and certainly not stations, locational information becomes more difficult to obtain. There are examples where motorists have reported legitimate highway deficiencies, and located them in the wrong direction on a divided highway, several miles from the actual spot, or by the wrong route number. Route junctions where several route markers are present seems to be especially confusing to motorists.

To get the maximum benefits from citizen reports, a plan should be developed with the following major features:

- Filing and collection of citizen reports - a plan should contain methods of informing the public as to where and how

V 2207

to file reports. This information could be disseminated by the news media and by bulletins posted in post offices or other public places.

- Instructions to those likely to receive complaints concerning what information is necessary to obtain from citizens and what to do with it.
- Analysis and followup of the report to determine if a hazard actually exists.

Detection of Slippery Conditions — Visual Indications

Visual indications of unreported accidents or near accidents are prevalent on the Nation's highways. One need drive only a short distance to observe destroyed guardrails, impact marks on barriers, indications of collisions with bridge supports skid marks on pavements, and skidding wheel track marks on grassy medians and shoulders. These indications should alert highway engineers that a skidding problem may exist. In the case of guardrails which are usually replaced when damaged, frequent replacement may indicate a slippery condition exists.

For example, an experimental surface material was placed on a section of U.S. Route 58 in the City of Danville, Virginia. The following is an excerpt taken from a report concerning the material:

> After the material was placed, numerous skidding accidents occurred. The median strip between the opposing lanes showed numerous skidding marks and appurtenances were damaged. Accident reports made many references to the material on the road surface.(29)

The concept of observing driver behavior on the road, such as hazardous maneuvers, abnormal number of brake light applications, and other patterns, may indicate something is amiss. These would indicate possible hazardous locations prior to an accident happening.

EXHIBIT 2201

CASE STUDIES OF ACCIDENT DATA USE

Pennsylvania

One of the specific uses of the accident data bank that Pennsylvania has had in operation since 1966 is the identification of wet-pavement accident locations.(30) Accident reports are received from state and local police and from those drivers involved in accidents. Accident forms used by the state and local police are almost identical. The local police are furnished the form by the state with the understanding that copies of all completed investigations will be forwarded to the state. Drivers involved in accidents resulting in death, injury, or property damage of more than $100 are required to file accident reports. These reports are used as those are filed by state and local police to build the accident data base.

Information included on the accident reports that may have been affected by wet-pavement conditions are:

- Severity
- Location
- Weather
- Pavement condition
- Vehicle type
- Collision diagram
- Description of the event.

V 2208

The credibility of subsequent analysis is greater as the quality and accuracy of the information provided by these reports improves.

The reference system established in Pennsylvania is based on station markers for the state highway system and on mile markers for the Interstate system. Highways are identified by legislative route numbers, rather than by traffic routes, because the legislative route system covers all highways under state jurisdiction and is the index for road logs and other records. Locations on other than state highways are identified by street name, township road name or number, and block face. A study of reported accidents indicates that 94 percent of those accident locations on the state system could be adequately located for remedial purposes with the location framework in use and that all but 2.5 percent of accident locations on other roadways could be located adequately by route name or cross route.

Reports received from police and drivers are correlated and given sequential identifying numbers. All papers referring to a particular accident are stamped with the same number, which is used to cross-reference driver files. After the analysis is completed the papers are filed by number for future detailed reference. From this comparison, reports can be grouped by county or city, which somewhat simplifies the location process.

As a first step in analysis, a team of about 15 people read the reports to determine the location as accurately as possible. The team depends primarily on large-scale county maps, but they also use all available reference material such as logs, telephone books, and street indexes.

Another group of about 15 analysts record the vital information for each accident for placement on magnetic tape. The analysts read the reports thoroughly and then form opinions as to what actually occurred.

As a result of the analysis, information pertinent to wet-pavement accidents are coded. This information includes:

- Location,
- Date,
- Weather,
- Road surface condition,
- Accident type,
- Identification of offending vehicle by type, movement, and causation factors,
- Identification of other vehicles involved,
- Severity of accident.

Cluster listings based on the criterion of 12 accidents or more within 1,000 feet during a three-year period are summarized for the state highway system. The figure varies with the time period being studied. The information is printed on a single line for each location and shows the county, legislative route number, limiting stations, number injured, number killed, and number of accidents. Engineering personnel, who are part of the surveillance team in each district, are assigned to review all locations on the cluster lists, to determine the relationship between the highway environment and the reported accidents, and to suggest counter-measures. Some of the clusters relate to wet-pavement accidents and are treated accordingly.

Tabulations are made of those sections of highway on which an apparently high proportion of accidents have occurred during wet weather. In these printouts the data is arranged by legislative route number and are subdivided by change in pavement type and abutting construction sections. Information is shown for the number of accidents, the rate per hundred million vehicle-miles of travel, the accidents per mile of road, and the percentage of accidents occurring on wet pavement.

As part of a "search-by-hazard" program, another type of cluster report is developed for accidents occurring on wet pavements. A minimum of five accidents must occur within a 3,000 foot segment of road during a three year period for the information to be listed.

The various printouts of wet-pavement accidents are studied, and a list of highway sections to be skid-tested is prepared for each engineering district. Two skid trailers are used in this statewide testing program, which includes tests on other sections reported to be slippery, retests, and research studies.

West Virginia

West Virginia, recognizing the seriousness of the skidding problem and concerned with its getting worse intensified development of anti-skid measures.

Skid-prone sites analyzed in a study had a wet accident rate ranging up to 40 times the statewide average wet accident rate and 85 times larger than the statewide average dry rate.(25)

After reviewing basic causes contributing to skidding such as polished surfaces, bleeding, fatty spots, and geometrics, it was concluded that other surface conditions or traffic characteristics peculiar to certain sites contributed to skidding.

Wet-dry accident ratios for night and day, for each county in the study area, at various degrees of curvature and pavement widths were analyzed. From the small sample, indications were that the wet-dry ratios by district and geometrics were closer to 2.0 percent than the statewide average of 2.2 percent, except for two highway districts and for 16 foot pavements and winding roads where the ratio was approximately 3.0 percent.

A problem was experienced with accident reporting. Not all highway traffic accidents subject to reporting were reported. Some did not precisely locate mileposts and approximately 10 percent of the accident forms did not include weather or pavement conditions.

The West Virginia program to implement anti-skid measures includes the following items:

- Identify sites by the various means available;
- Examine sites and available records for various contributing causes and conditions;
- Determine practicable corrective measures;
- Discriminate among aggregates for feasible skid-resistant types;
- Set minimum specifications for all wearing surfaces;
- Attempt correlation among wet-pavement accdents, skid number, roadway condition, ADT, geometry, access, and other relevant parameters;

- Determine skid numbers required for various geometry, operating speeds and ADT;
- Determine effect of change in skid number on accident rate through before-and-after studies and long-range trend studies;
- Reduce both the number of incidents and accidents;
- Develop statewide portrayal of skid number demands for each highway section for periodic comparison with actual skid-number value to determine when decline is below critical level.

Factors that may contribute to a skidding accident were listed at the beginning of this section. Many combinations of these factors can produce an accident, but all required conditions for a skid must be present if a skid is to occur. If all required conditions except one exist, the skid will not take place. A skid-resistant surface can often provide the exception that prevents the accident.

Sudden changes in speed or direction induce skidding. This happens when incipient skidding exists and sliding is initiated in changing direction or speed. Whenever the kinetic forces exceed the coefficient of friction between tire and pavement, a sliding state results. This condition can occur when there is either gradual or sudden transition of pavement skid number from adequate to inadequate. This condition can be made to occur with dramatic suddenness when the driver, possibly because of a change in highway geometrics, changes an adequate pavement-tire friction interaction to an inadequate one by suddenly increasing the frictional demand above that available. In the first instance, the skid number decreases below a constant demand. In the second instance, the demand increases above a constant skid number. In some cases both conditions may occur simultaneously.

The tire-pavement interaction is the controlling feature in skid resistance, and the demands at grades, curves, intersections, and areas of free access can require the highest feasible skid number.

In the accident reduction strategy the use of annual accident records together with geometrics were used to discover sites of excessive wet-pavement accidents.

Skid prone sites are identified through accident records, police alerts, district engineers' reports, news media reports, and citizen complaints. Occasionally near-accidents such as "fishtailing" and other skidding incidents are reported that do not result in property damage or injury.

By computer scanning it was possible to locate sites having three or more wet-pavement accidents for each half mile section of highway, constituting 30 percent or more of the total number of accidents in that section. The reported half-mile section, with the half-mile sections abutting on each end, was scanned by one tenth-mile increments to see if there were accident clusters within short distances indicating possible skid-prone sites.

BEST DOCUMENT AVAILABLE

2201

PURPOSE OF TRAFFIC ACCIDENT RECORDS

- Assess Damage
- Identify Problems
- Suggest Countermeasures
- Evaluate Countermeasure Effectiveness
- Determine Liability

2202

ACCIDENT RECORDS USERS

- Police
- Courts
- Legislators
- Transportation Departments
- Motor Vehicle Departments
- Insurance Firms
- Involved Individuals
- Attorneys

2203

SKIDDING ACCIDENT FACTORS

- Instantaneous Speed
- Acceleration/Deceleration
- Centrifical Force
- Steering Angle
- Tire Type/Conditions
- Driver Behavior

2204

SKIDDING ACCIDENT FACTORS

- Surface Texture
- Visibility
- Volume/Density of Traffic
- Speed
- Traffic Control/Regulation
- Weather

2205

IMPROVEMENT PROGRAM

- Field Reference System
- Traffic Records System
- Identification and Reporting Procedure

2206

ACCIDENT DATA SYSTEM

- Filing System
- Locational Information
- Agency Responsibility
- Summarize and Correlate
- Identify Hazardous Locations
- Quick Distribution of Information

2207

CITIZEN INPUT

- Where
- How
- What

→ To File

- Analysis and Follow-up

2208

ACCIDENT REPORT INFORMATION

- Date/Time
- Daylight/Darkness
- Weather
- Pavement Type
- Pavement Condition
- Location
- Vehicle Type
- Description of the Event
- Property Damage/Injuries/Fatalities
- Collision Diagram

BEST DOCUMENT AVAILABLE

2209

ACCIDENT RECORDS

- Identify Driver Problems
- Assist in Development of Driver Education Programs
- Identify High Accident Locations
- Identify Highway Deficiencies
- Assist Legislative Bodies in the Preparation of Laws and Ordinances

2210

ANTI-SKID PROGRAM OBJECTIVES

- Identify Sites
- Determine Countermeasures
- Set Minimum Specifications
- Determine Skid Number Criteria

Reduce Accidents

SESSION 23

INSTRUCTION Guide

EQUIPMENT - Slide Projector

AIDS: Slides 1 to 12 listed in Aid 2301

APPROACH: Skid testing in U.S. almost universally based on ASTM 274.

Some background information on other methods. Devote short periods to the SCRIM, the Automobile Method, Portable testers etc.

Devote majority of session to the locked wheel method (ASTM 274) with lesser emphasis on the Mu-meter.

Slides may be shown at the end of the session but should be referred to during the session.

EMPHASIS

Basic difference in concept of friction resistance in the locked wheel method and the Mu-meter approach.

Results obtained from different methods are not directly comparable as the basic force being measured is different, apart from differences in mechanical and measurment techniques.

SESSION 23

AID: 2301

SLIDES:

2301. Original Skid Tester (see Bureau of Public Roads)

2302. Motorcycle with Side Car - English Skid Tests.

2303. Close Up of Motorcycle Showing Testing Wheel.

2304. Citroen Car - Note 5th Wheel in Center.

2305. Two Modern Skid Testers.

2306. Closer Shot of FHWA Tester.

2307. Closer Shot of the Skid-Trailor - Note Water Jet Pipe, Etc.

2308. Trailor in Motion Showing Water Path.

2309. Inside of the Cab - FHWA Tester.

2310. Mumeter - Note Recording Device.

2311. Another Shot of Mumeter - Note Water Jet Pipe.

2312. Mumeter - Showing Recording Devices.

SESSION GUIDE

SESSION: 23. DETECTION OF SLIPPERY CONDITIONS - SKID TESTING

SESSION OBJECTIVES:

At the conclusion of this session, participants will understand the different methods of skid testing and the equipment necessary to perform the tests. They will also be familiar with ASTM Standards E 274, E 445, and E 670 which are the test methods used in the United States.

REFERENCES: 1, 3, 31, 32, 33, 34, 35

CONTENT:

Skid Testing Methodology 23-2

Skid Testing 23-3

Detection of Slippery Conditions by Skid Testing 23-13

SKID TESTING METHODOLOGY

Skid testing methodology in the United States is almost universally conducted in accordance with ASTM (American Society for Testing and Materials) standard E 274.(31) Stated in the scope of the method are the following points:

Based on ASTM 274

- The method covers the measurement of skid resistance of paved surfaces with a specified full-scale automotive tire.
- The method utilizes a measurement representing the steady state friction force on a locked test wheel as it is dragged over a wetted pavement surface under constant load at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement.

Although this specification may be met by a system involving only one wheel attached to a towing vehicle, and although a few such systems are known to be in use, the vast majority of skid measurement systems in the United States consist of a towing vehicle and a two-wheel trailer. On most systems either wheel may be locked during testing, but most commonly the left wheel is used.

A skid measurement system must have (1) a transducer associated with each test wheel which senses a force equal or directly related to the force developed between the sliding wheel and the pavement during test, (2) electronic signal conditioning equipment to receive the transducer output signal and modify it as required, and (3) suitable analog and/or digital readout equipment to record either the magnitude of the developed force or the calculated value of the resulting skid number(SN).

The system must include the facility for the transport of a supply of water — usually 200 to 500 gallons (750 to 1900 liters) and the necessary apparatus to deliver approximately 4 gallons (14 liters) of water per minute, per wetted inch (25 mm) of pavement at 40 mph (65 km/hr) within specified limits in front of the test wheel.

Finally, the system must include provision for measurement of the speed at which the test is conducted.

SKID TESTING

Since the origin of skid testing in the early 1930's, two major methods of skid testing have developed around the world. Although there are a number of devices for performing the tests, common methods measure either the sideway-force coefficient or braking-force coefficient of friction.

With a few notable exceptions, the primary method for skid testing in the United States is the locked-wheel braking machine. This is not the case in Europe and other parts of the world. A brief discussion is inserted below describing the common testing method used abroad.

Sideway-Force Coefficient (England)

The Sideway-Force coefficient (SFC) is measured by a machine appropriately referred to as the Sideway-Force Coefficient Routine Investigation Machine, and is almost universially referred to by the initials SCRIM.

The development of machines to measure SFC passed through several phases following the use of the early motorcycles (see slide session 11). The first of these was the incorporation of a fifth wheel in a front-wheel drive car. A citroen car was the first production vehicle found to be suitable. In the early 1960's a suitable British car became available.

The test vehicle measures sideway-force that is generated by a test-wheel running at a 20 degree angle to the direction of travel of the vehicle. The vehicle utilizes a smooth tire in its measurements. The vehicle is mounted on a production commercial vehicle chassis and its essential feature is a 700 gallon (2,700 liter) water tank, a quantity sufficient for 1/2 day testing or 30 miles (50 km).

The test wheel has its own deadweight, spring, and shock absorber to give a known static reaction between tire and road. In the hub there is an electrical load cell to provide the sideway-force input to the recording system. A speed input is provided from the vehicle transmission system.

Output, on magnetic or punched paper tape, consists of a record at 16ft.(5m), 32 ft.(10m), or 65 ft.(20m) intervals of SFC, speed, and data to indicate location of the test. The recorder is fitted with facilities for calibration of the system, and the unit is mounted in the vehicle cab for operation by a technician accompanying the driver.

Method Used in The United States — Locked Wheel Trailer

It cannot be overemphasized how important it is, even in routine work, to adhere to standardized procedures for determining skid resistance.

Control of variables

Although pavements are essentially rigid as far as skid resistance is concerned, surface characteristics change with time and are frequently far from uniform. Unless repeat measurements are made in an identical manner, changes may be thought to have occurred that actually have not, causing the magnitude of real changes to be distorted.

The scope of ASTM Committee E 17 on Skid Resistance includes the development of standard methods of measuring available skid resistance. This committee is responsible for ASTM standare E 274.

By using a tire representative of those most commonly used on vehicles, it is thought that the results of skid resistance tests can be directly applied to the performance of vehicles in traffic. This is only an approximation for several reasons that will be discussed later in the section. However, the differences in tire performance and the numerous tires available for one vehicle model leaves any generalization open for error. These difficulties are not overcome, but comparison of the skid resistance of different pavements becomes possible, if a standard tire is used. In the United States, the standardized skid test tire is that defined by ASTM standard E-501. It is a bias-ply 7.50 x 14 tire with seven circumferential grooves. The standard rigidly prescribes the rubber composition. Thus, the tire type and design are eliminated as variables in the measurement of pavement skid resistance.

ASTM Standard Test Method E 274 describes how this tire is to be used when measuring skid resistance of highway pavement surfaces by the locked-wheel method. It requires that the test tire be installed on the wheel or wheels of a single- or two-wheeled trailer. For a measurement, the trailer is towed at a speed of 40 mph over the dry pavement and water is applied in front of the test wheel. The ASTM method specifies the method of applying the water and other details. The test wheel is locked up by a suitable brake, and after it has been sliding on the pavement for a certain distance (to permit the temperature in the contact patch to stabilize) the force that the friction in the tire contact patch produces and transmits as torque on the test wheel is measured by suitable means and recorded for a specified length of time. The result of such a test is reported as skid number(SN 40).

Many states, universities, and private organizations now have skid trailers. Although most conform to ASTM method E 274, only a few are identical. Therefore, some differences exist between them. Almost all are permanently paired with a towing vehicle that carries a water supply, instrumentation, and other necessary equipment. These units might be referred to as Road Friction Testers.(3)

Variables still affect the results.

Skid resistance measurements are not as unequivocal as this description might suggest. Seasonal variations exist as is shown by several studies. For instance, even though the standard tire has been found to be very uniform, friction of rubber is temperature dependent, as are tire characteristics. It would not be difficult to standardize measured skid numbers for a single temperature In reality, there is a complicated interplay that involves air, pavement, water temperatures, the heating of the tire structure by flexing, and the heating of tread by friction. Thus, no universally accepted method of correcting skid number for temperature exists as yet.

There are other potential error sources, some of which affect the repeatability of test made with the same tester, whereas others cause different testers to give different results on the same surface under the same conditions.

These imperfections, however, do not diminish the usefulness of ASTM method E 274 for most purposes, such as (1) determining whether or not pavement slipperiness is a governing or controlling factor at highway-accident locations, (2) making surveys of a road system for the purpose of identifying slippery sections and setting priorities for remedial programs, and (3) determining the relative in-service skid number of different types of construction, aggregates, and surface treatments. Difficulties arise only when high precision is needed, as in determining whether a particular surface does or does not meet a mandated level of skid resistance.

This is why minimum skid numbers are generally not mandated.

Automobile Method

Another method of determining the skid resistance of a pavement is to drive an automobile on it, lock up the wheels, and measure how far it slides until it comes to a full stop. There are advantages and disadvantages to this method. Its main advantages are low capital investment and ready availability. A major disadvantage is that it is potentially hazardous, particularly if high-speed tests are to be made.

The hazards can be reduced by not braking all wheels. When all four wheels are locked, the vehicle becomes unstable. Any small disturbance can cause the vehicle to veer from its intended path. By braking the front wheels only, or a diagonal pair of wheels, the risk of spin-out is significantly reduced.

Arguments arise that not braking all wheels is unrealistic because it does not show how far an automobile would slide in an emergency. This is correct, but even if all four wheels are locked for the test, it is still not feasible to deduce the stopping distance of vehicles in traffic from the results. The locked-wheel stopping performance among vehicles differs significantly because of differences in vehicle design, suspension design, tire types, vehicle condition (particularly the condition of shock absorbers), tire inflation pressure and tread wear, vehicle payload and distribution, etc. For this reason it is also difficult, with any degree of accuracy, to estimate from tire tracks the speed a vehicle was traveling prior to an accident.

Nevertheless, if they are made carefully locked-wheel automobile tests can serve for characterizing and comparing pavement surfaces. To eliminate tires as a variable, such tests are generally made with the ASTM E 501 standard pavement test tire, if only because it is difficult to procure commercial tires of adequate uniformity over long periods of time.

A disadvantage of locked-wheel automobile tests for assessing the skid resistance of wet pavement is that one must depend either on rain or on a sprinkler truck. Neither assures the controlled water film thickness that is obtained with a road friction tester. The cost of a sprinkler truck adds significantly to the apparently low unit cost of the automobile test.

These tests can be carried out in various manners. One can measure the distance the vehicle travels from the point at which the wheels cease to rotate, or from the point at which the vehicle, with wheels locked, passes through a specified speed to the point at which the vehicle stops. One can measure the distance or the time the vehicle requires for decelerating from one speed to another, say from 30 to 20 mph. Deceleration can be measured directly with a suitable instrument, and either the deceleration at a certain point in the test cycle or the mean deceleration over a stated portion of the cycle can be used to characterize the pavement tested.

In comparing the results of any automobile method with those from a locked-wheel skid tester, it must recognized that the automobile decelerates during the test, but the road friction tester does not. However, if they are used correctly, the automobile methods tend to give more consistent results than those obtained with road friction testers. This is largely accounted for by the fact that on the automobile a single reading averages the performance of four (or at least two) tires, whereas on locked-wheel test trailers, normally only one wheel is locked.

Consistency achieved due to "averaging" effects by not testing in the "most travelled wheel path"

At stops from high speeds the vehicle has air drag in addition to the resistance at the tire-pavement interface. In still air and with an aerodynamically clean car this is of minor importance, especially in direct comparison tests, but when there is wind, the magnitude of the error becomes elusive. Load transfer to the front axle during a stop is not important if front and rear wheels are locked. For this reason, the diagonal braking method is preferred if all wheels are not to be braked. Because the friction factor is slightly load dependent, braking only one axle may introduce a systematic error (especially if the vehicle has a high center of gravity) and a variable error (if the static load distribution is permitted to vary).(1)

ASTM Committee E 17 has developed E 445-76 as a recommended method for automobile tests.(32)

The Mu-meter

The Mu-meter is a friction measuring trailer which has been gaining in popularity recently, and is being used by various states on a permanent basis as part of their skid resistance measurement programs. The reasons for this gain in popularity are easy to see as the following lists of advantages and disadvantages of the Mu-meter will highlight.(33)

Advantages

- Inexpensive compared to other skid trailers, with low operating costs.
- Capable of testing 250 lane miles per working day.
- Rugged, completely mechanical in operation, and therefore, high reliability and little downtime.
- Results correlate well with other skid trailers, and to stopping distance cars.
- Test results have high "repeatability".

Disadvantages

- ASTM E 670-79, the Standard for the Mu-meter has been established recently and little data exists using this standard.(34)
- Measurements are based on sideway forces.

The original Mu-meters were devised as static friction measuring devices for use on airport runways. The FAA uses the Mu-Meter as the standard method for measuring friction on airport pavement. The Mu-Meters now in use by various states for highway work have been adapted to provide continuous output while being towed and have had their own water supply systems added.

Since the standard for the Mu-meter is very recent, the following description is based on the modified Mu-meter used by the Arizona Highway Department in a study of surface friction in 1972. The Mu-meter is essentially a two-wheel trailer with the wheels at a fixed tow-out angle of 7-1/2 degrees, and a third recording wheel. Since both wheels are at the same and opposite tow-out, the trailer is easy to tow. Pulling the Mu-meter causes a sideway friction force which is sensed by transducers and then transmitted by a hydraulic pressure system to a Bourdon gauge and automatic recording mechanism. Since all the recordings and control equipment is located in the cab of the towing truck, the Mu-meter in this modified form becomes a versatile tool where tests can be made without stopping or interfering with traffic.

The addition of a watering system with a control valve which allows a controlled amount of water to be applied to the test wheels completes the system.

The Mu-meter as used by Arizona was filled with a smooth tire and thus the water required to represent a wet roadway was much less than that required for a standard ribbed tire (the new standard now specifies tire type and water application).

The following basic differences existed in the Mu-meter approach and the ASTM 274 approach of measuring Skid Resistance:

Mu-meter

- Used smooth tire. (now standarized to ribbed tire)
- Measured sideway friction force.
- Tire temperature was not standardized.
- Water applied was one of the test variables (now standardized).
- Output is in terms of Mu (friction number).
- Measurements are an average of two wheels - only one of which can be in the "most traveled wheel path."

ASTM 274

- Uses standardized rubber test tire.
- Uses direct drag resistance.
- Test wheel dragged for distance to stabilize temperature.

- Applies standard amount of water to wheels.
- Output in terms of skid number.
- Test in "most traveled wheel path."

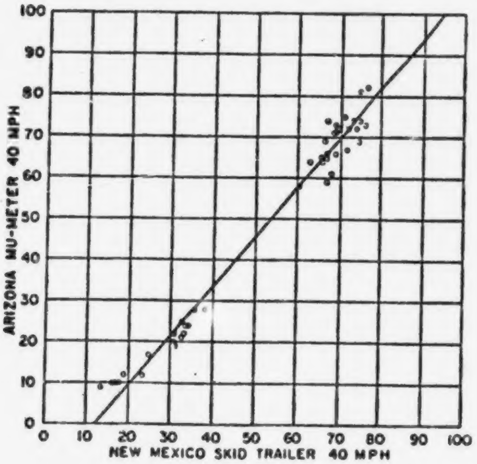
Considering these differences, the results achieved by the Arizona Tests correlated very closely with the ASTM 274 Method Mode, and it was found that Mu factors could be converted to skid numbers by a very simple equation with a high degree of consistency.

A similar correlation was determined with a standard skid car and with another (slightly different) Mu-meter used by Utah.

As examples, Figures 23-1 and 23-2 show two of the relationships achieved in the Arizona study (31).

FIGURE 23-1

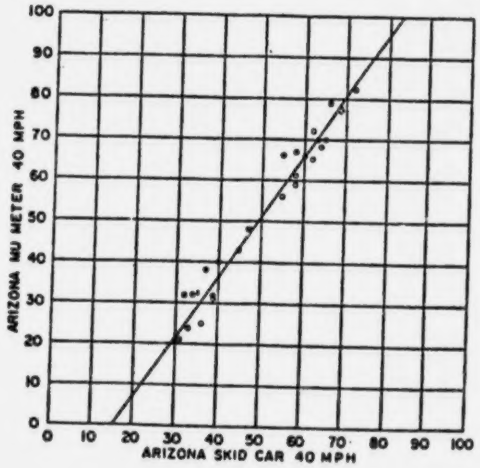
NEW MEXICO SKID TRAILER CORRELATION
SEPTEMBER 14, 1971



Number of cases = 42
Mu-Meter = −14.939 +1.2105(Skid Trailer)
Skid Trailer = 12.341 + 0.8261(Mu-Meter)
Correlation coefficient = 0.9897
Standard error = 3.16 N.M. values

FIGURE 23-2

SKID CAR CORRRELATION
JANUARY 1972



Number of cases = 26
Skid Car = 15.219 + 0.6777(Mu-Meter)
Mu Meter = −22.456 + 1.4755(Skid Car)
Correlation coefficient = 0.9802
Standard error = 2.72 Car values

Note that these relationships are not universally applicable, and that the study was carried out before the setting up of the Field Test and Evaluation centres.

In conclusion, the Mu-meter seems to have good potential as a valuable skid measuring device. The major factors holding back its wide acceptance are the lack of standard data from its operation, and the basic question of whether measurement of skid resistance should be in terms of stopping distance in a straight line or in terms of a sideways slip force.

Portable Field Testers

The cost of road friction testers and the problems inherent in high-speed tests have repeatedly led to the development of so-called "portable" testers: machines that are not operated by or as a moving vehicle, but can be moved readily from location to location. They are not laboratory devices that are used on the highway, but units specifically designed for highway use.

The California Skid Tester - operates on the principle of spinning a rubber-tired wheel while it is off the ground, lowering it to the pavement, and noting the distance it travels against the resistance of a spring before it stops. The device is attached to the rear of a suitable vehicle, which is stationary during a test, permitting it to be easily placed. The tester is normally operated with glycerine instead of water as the pavement lubricant. This is done because glycerine insures a longer lasting, more uniform film.

The Drag Tester - is a hand-carried device developed by Pennsylvania State University and marketed as Keystone Tester. It employs a rubber shoe that slides along the pavement as the operator "walks" the tester. The frictional resistance experienced by the shoe is converted to hydraulic pressure and displayed on a gauge. Water must be applied to the pavement ahead of the tester by suitable means.

These two examples show how completely different principles can be employed as friction testers. The number obtained with them may be similar to, or may differ greatly from, those obtained by other methods. Approximate agreement among differing types of testers can be achieved by suitable dimensioning of the operating elements or choice of the readout scale. Perfect correlation between testers must not be expected if the operating principles and/or modes differ.

The advantage of portable testers is that they can be inexpensive, therefore a large number of operating units can be equipped with means for measuring friction. They also permit friction to be measured in locations where a road friction tester cannot be operated. They permit testing pavement markings and checking the transverse change in the friction factor across a highway or lane.

Portable testers, because they do not employ or adequately simulate locked-wheel testers, cannot substitute for the latter, but they can serve as useful supplements.

Laboratory Testers

Researchers have devised innumerable devices and machines for measuring friction in the laboratory. Special objectives and conditions govern their design and limit their usability for purposes other than those they were intended for. However, one design that is extremely versatile in its applicability to many test situations and, in consequence, has attained wide use, is the British Portable Tester, developed by the Transport and Road Research Laboratory (TRRL) in Britian. It consists of a pendulum to which a spring-loaded rubber shoe is attached. By letting the pendulum drop, the shoe is made to slide over the surface to be tested. The attenuation of the rebound serves as a measure of the friction. The results are reported as British Pendulum Numbers (BPN) to emphasize that they are specific to this tester and not directly equivalent to those obtained by other methods or testers.

One advantage of the British Portable Tester is that it can be used not only in the laboratory but also on the highway. It was used for this purpose rather extensively in the past, before trailer-type road friction testers became widely available. The ability to be used in the laboratory on cores and other test specimens, as well as on the highway, is a decided advantage of the pendulum tester. A factor limiting its use on the highway is that setting it up and getting it ready for measurement is a rather lengthy process, and traffic must be stopped or diverted. In addition, because it is a low-speed device (the rubber shoe contacts the pavement at a speed of about 7 mph) and because only a narrow rubber edge contacts the pavement, it does not correlate well with locked-wheel trailers that operate at 40 mph or more.

DETECTION OF SLIPPERY CONDITIONS BY SKID TESTING

Skid testing may be performed for a wide variety of reasons. But the primary reason is to detect slippery pavements which may be corrected to prevent accidents. To use skid test equipment to detect slippery pavement conditions the term "Slippery" must be translated into skid numbers. While virtually no state, because of the potential legal liability, will specify a minimum skid number, there are a range of skid numbers that are obviously unsafe. In order for skid testing to be used as an effective tool decisions have to be made, at least within a transportation department, as to acceptable skid numbers. This becomes further complicated when variation in friction demand by type of location is taken into consideration as discussed in previous sections.

States have in fact developed ranges of skid resistance values they strive to obtain. They may vary by classification of road, by traffic volume, or for any other valid reason. The frequently referred to NCHRP Report 37(3) suggests skid values for various speeds.

Various states and jurisdictions had previous to NCHRP Report 37, or since, derived rationally, on the basis of available data and information, skid resistance values based on their own considerations, frequently on intuitively condensed experience, and sometimes with provisions for higher values at specified locations. Interestingly enough, such standards and guidelines agree, on the average, with the recommendations of NCHRP Report 37.(1)

Short of a systemwide skid inventory system, additional information obtained about pavements will benefit the skid test program and can optimize the detection of slippery conditions with a limited skid test program. If the state or jurisdiction has a pavement data bank, pavement information can be obtained readily. Otherwise it may be more difficult to compile, but it is still worth the effort necessary. Pavement information useful in indicating whether to test in a limited program is as follows:

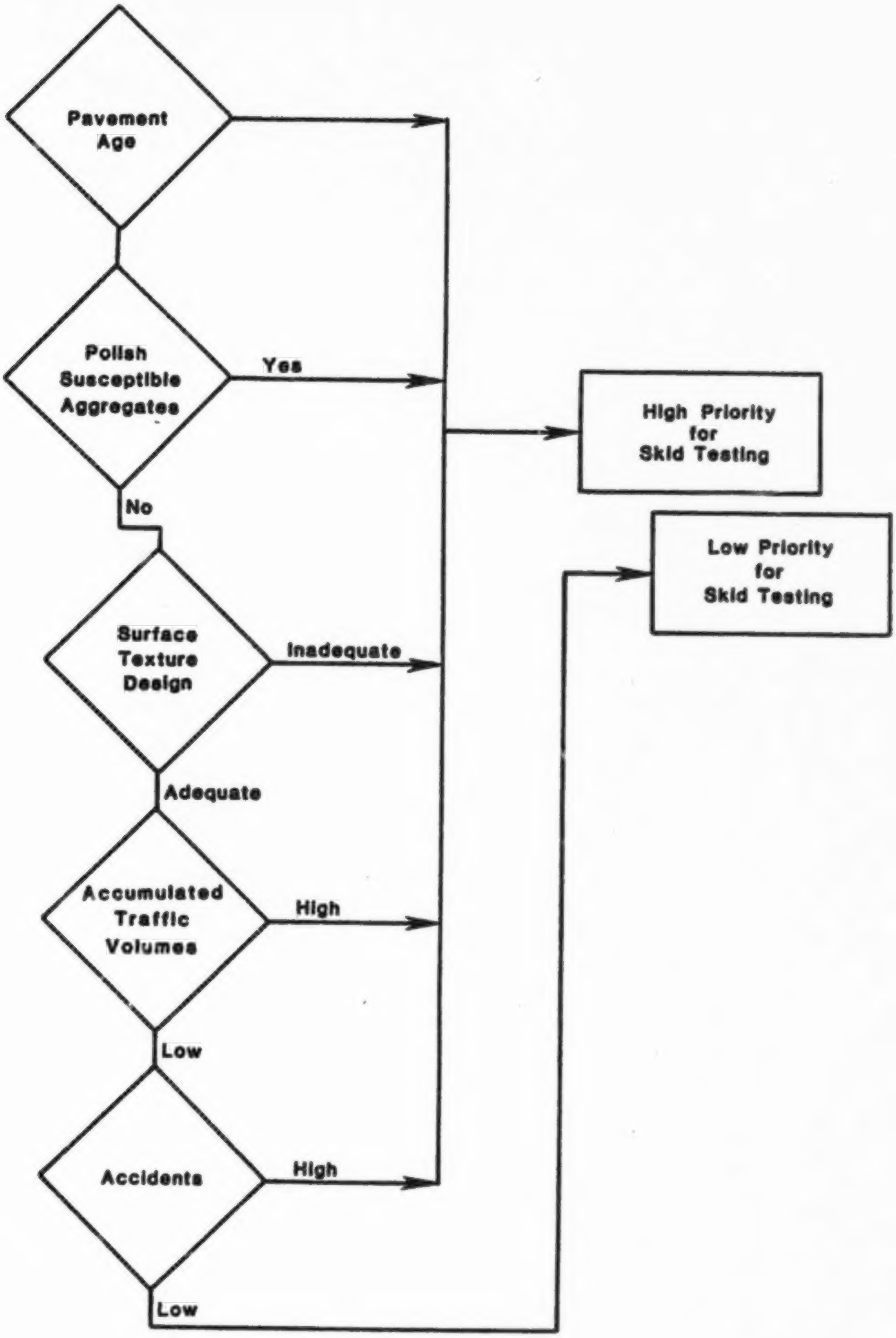
- Pavement Age - there is no such thing as a non-polishing pavement surface. Therefore, virtually all pavements become polished to some degree with age and traffic wear.
- Aggregate Type - there is general knowledge in the highway industry about the polish susceptibility of certain classes of aggregates used in paving materials. For example, it is well known that many limestones and dolomites polish readily under heavy traffic.
- Surface Texture - It has been satisfactorily proven that concrete pavements finished with one drag of a burlap bag will become slippery after 20 to 25 million vehicle passes.(35)

Logic For Establishing Priorities For Skid Testing

Closely allied with pavement data as an indicator of the potential development of slippery conditions is traffic volume data. There is no doubt that pavement surfaces polish as the result of accumulated traffic wear. Environmental degradation affects pavement slipperiness but the prime cause of slippery pavements is accumulated traffic wear. For this reason accumulated traffic volumes will help optimize selection of skid testing locations for slippery conditions. Finally, by combining whatever accident data is available, a logical testing sequence may be established as illustrated in Figure 23-3.

FIGURE 23-3

LOGIC FOR ESTABLISHING PRIORITIES IN SKID-TESTING


Pavement Age
Polish Susceptible Aggregates
Yes
No
Surface Texture Design
Inadequate
Adequate
Accumulated Traffic Volumes
High
Low
Accidents
High
Low
High Priority for Skid Testing
Low Priority for Skid Testing

SESSION 24

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraph 2401

Teaching Aid 2401 - reprint from NCHRP 151.

Teaching Aid 2402 - reprint from NCHRP 151.

APPROACH: Importance of calibration.
Error sources and relative magnitudes of these can be found in Teaching Aid 2401

V 2401 shows major calibration procedures used at Field Test and Calibration centers.

Finish session by using Teaching Aid 2402 to show how errors can add up to unacceptable levels if variables are not rigidly controlled.

TABLE 8

SUMMARY OF FACTORS IN SKID RESISTANCE MEASUREMENT

ERROR SOURCE RANDOM	SYSTEMATIC		MAXIMUM EFFECT	AVERAGE ERROR BAND		CORRECTIVE ACTION	REDUCED ERROR BAND	
				FACTOR	SKID RESISTANCE		FACTOR	SKID RESISTANCE
X		Speed holding (1) *	At 40 mph ±1.2 SN per mph	±2 mph	±1.5 SN	Speed deviation indicator	±1 mph	±0.8 SN
	X	Speed measurement (1)	Same	±5%	±1.5 SN	Fifth wheel and a) tachometer-generator b) pulse-generator	 ±2% ±0.5%	 ±0.8 SN ±0.2 SN
	X	Water temperature (1)	Negligible					
	X	Air temperature (2)	Indirect effect through pavement and tire temperature.					
X		Pavement or tire temperature (2)	±4%/10° F	Depends on season and geographical region	±2%/10° F	Correction requires accurate skid resistance and temperature measurement		±1%/10°F
X	X	Water film (3)	±1 SN for ±10% variation	±25%	Negligible on most pavements, on some ±2.5 SN	Specify calibration method, reduce tolerance to ±5%	±5%	Negligible on most pavements, on some ±1 SN
	X	Water flow (3)	Strong	Large		Uniform watering system, calibrated flow rate proportional to speed		Negligible
X		Pavement variability, (4) lateral	10 SN	15 in.	±4 SN	Operator awareness	5 in.	±2 SN
X		Pavement variability, (4) longitudinal	7 SN in mile		±2 SN	Number of samples (wheel-locks) per test based on standard deviation of tester		±2 SN
X		Conditioning and deterioration (4)	4 SN per day		−2 SN	Run control tests, randomize test sequence, correct data		−1 SN
	X	Tire variability (5)	2.5 SN		±1 SN	Check before use		±0.5 SN
	X	Tire construction (5)	2 SN		±1 SN	Belted tire		±0.5 SN
	X	Tire condition (5)	Within wear range 1 SN		±1 SN	Check for uniform wear		±1 SN
	X	Inflation pressure (5)	1 SN in operating range	24 to 28 psi	1 SN	Use reliable gage		1 SN
	X	Wheel-load error (6)	% SN error equal to % weight error	±2%	±2%	Use scale of minimum resolution of 5 lb	±0.5%	±0.5%
	X	Wheel-load range (6)	1 SN/100 lb	880 to 1080 lb	2 SN	Reduce range		1 SN

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TABLE 8 (Continued)

ERROR SOURCE RANDOM	SYSTEMATIC		MAXIMUM EFFECT	AVERAGE ERROR BAND FACTOR	AVERAGE ERROR BAND SKID RESISTANCE	CORRECTIVE ACTION	REDUCED ERROR BAND FACTOR	REDUCED ERROR BAND SKID RESISTANCE
X		Dynamic wheel-load change (6)	2 SN		±1 SN	Avoid aerodynamic loads, wheel-load recording with electronic evaluation		±0.5 SN
X	X	Instrumentation (7)	Drift		10% or more	Reliable instrumentation, observing operating procedure		±1%
X	X	Operating procedure (8)		Controls other error sources		Follow correct procedure		
	X	Torque calibration (9)	Negligible			See procedure		±0.5% (±2 lb)
	X	Platform calibration (9)	±10%		±4.5%	See procedure		±2% (±5 lb)
X	X	Data eval.: (10) Operator	±5 SN		±3 SN	Adequate resolution, correct operating procedure		±1 SN
	X	Braking cycle	±2%	Minimum cycle 2 sec	±2%	Optimal filtering increase interval	Minimum cycle 3 sec	±1%
X		Dynamics (11)	Negligible direct effect					
		Statistical control (12)		Repeat tests		Estimate standard deviation of tester, determine number of repeat tests	Repeat tests	

[a] Numbers indicate corresponding sections in Appendix A.

among skid testers, and s_A as the standard deviation in skid testing. The latter includes interactions of skid testers and pavements and can also be computed from the definition of variance:

$$s_A^2 = \frac{1}{n-1}\left[\Sigma \mathrm{SN}^2 - n(\overline{\mathrm{SN}})^2\right]$$

The reductions in standard deviations, discussed in Chapter 2, are summarized in Table 10 for both s_T and s_A.

CONFIDENCE CRITERIA FOR A SKID TEST PROGRAM

Previously precision and accuracy were discussed, and it was concluded that lack of precision results from random errors and lack of accuracy from systematic errors. Individual error sources have also been discussed and classified.

Systematic errors are present when results of skid tests that are conducted under identical conditions by two or more skid testers, or by a single tester in successive tests, differ significantly. A difference is considered significant when it exceeds the statistical limits ascribable to random errors, which will be discussed later. To correct for systematic errors, the error source should preferably be eliminated or a correction factor can be applied to the data.

TABLE 9

ESTIMATED AND COMPUTED STANDARD DEVIATIONS

TEST CONDITION	STANDARD DEVIATION COMP. s_T [a]	STANDARD DEVIATION COMP. s_A [b]	STANDARD DEVIATION EST. s [c]
Single tester, five repeated tests:			
Uncorrected	—	1.43	4.1
Corrected	—	1.12	1.7
Correlation program:			
Uncorrected	4.08	4.96	2.9
Corrected	1.04	1.60	1.3

[a] s_T^2 is tester variance.
[b] s_A^2 is skid testing variance.
[c] See Appendix I.

Statistical treatment of data *cannot* correct for systematic errors.

Random errors are evidenced by a large data spread and can be recognized by analyzing the data of a single tester. Such errors can be reduced in part by eliminating error

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APPENDIX I

ESTIMATE OF ERROR IN SKID TESTING

Error sources and the estimated errors in skid testing are given in Table I-1. All estimates have been made for a pavement of average skid resistance (between 40 and 50 SN) and a test speed of 40 mph. Two estimates of error are given; the first, "as is," is based on review of skid resistance data for several representative skid testers; the second, "reduced," is an estimate of reduced errors resulting from improved procedures, correction of data, and, in some cases, improved equipment.

Normally all or some of the errors act simultaneously and an estimate of the combined effects has been made for three modes of testing, which are given in Table I-2. Modes 1 and 2 are for a single tester in repeat and survey testing, respectively. It is assumed that a few tests have been run for preconditioning and are not included in the data. It is also assumed that all tests are made within a short period of time. The computation includes only those errors that may vary from test to test. Thus, the computed error band is about the mean skid resistance measured by the same tester, which may be far from the mean measured by any other tester. The error band is a measure of precision only.

In testing modes 3(a) and 3(b), the combined error

TABLE I-1

ERROR SOURCES IN SKID TESTING AND THE ESTIMATED ERROR BANDS AT 40 MPH, AS IS AND REDUCED BY CORRECTIVE ACTION

SYMBOL	ERROR SOURCE	ERROR ESTIMATED (SN)	
		AS IS	REDUCED
X_1	Speed holding	±1.5	±0.8
X_2	Speed measurement	±1.5	±0.8
X_3	Temperature	±4	±2
X_4	Water film	±2.5	±1
X_5	Lateral position	+4	+2
X_6	Longitudinal position	±2	±2
X_7	Pavement conditioning and deterioration	−2	−1
X_8	Variability among tires	±1	±0.5
X_9	Tire construction	±1	±0.5
X_{10}	Tire condition	±1	±1
X_{11}	Inflation pressure	±1	±1
X_{12}	Wheel load error	±1	±0.2
X_{13}	Wheel load range	±2	±1
X_{14}	Dynamic wheel load	±1	±0.5
X_{15}	Calibration error	±3	±0.5
X_{16}	Operator data evaluation	±3	±1
X_{17}	Procedure of data evaluation	±2	±1

TABLE I-2

PREDICTED TOTAL ERROR BANDS FOR THREE MODES OF TESTING CONDUCTED IN BOTH AS-IS AND REDUCED CONDITIONS

TOTAL ERROR BAND $=\left[\sum_i x_i^2\right]^{1/2}$, x_i—INDIVIDUAL ERROR BANDS.

MODE	FACTORS	ERROR BAND (SN)		ERROR BAND (SN) FOR MEANS OF FIVE REPEAT TESTS		ESTIMATE, s_4			
						MEANS		SINGLE TESTS	
		AS IS	RE-DUCED	AS IS	RE-DUCED	AS IS	RE-DUCED	AS IS	RE-DUCED
1. Repeat testing by single tester	$X_1, X_4, X_8, X_{14}, X_{16}$	9.5	4.0	4.2	1.8	1.8	0.8	4.1	1.7
2. Inventory testing by single tester	$X_1, X_4, X_5, X_6, X_{14}, X_{16}$	10.5	5.6	4.0	2.5	2.0	1.1	4.5	2.4
3. (a) Tester comparison	$X_1, X_2, X_3, X_4, X_5, X_7, X_8, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}$	15.8	7.3	7.0	3.3	3.0	1.0	—	—
(b) Correlation program	$X_1, X_3, X_4, X_6, X_7, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}$	15.3	6.8	6.8	3.0	2.9	1.3	—	—

SESSION GUIDE

SESSION: 24. SKID TEST EQUIPMENT CALIBRATION AND CORRELATION

SESSION OBJECTIVES:

At the conclusion of the session the participants will be able to detect skid test equipment malfunctions and be aware of calibrations that can be performed in-house. They also will be familiar with the location and function of the Field Test and Evaluation Centers and the services they provide.

REFERENCES: 36, 37, 38

CONTENT:

Calibration and Correlation 24-2
Calibration Procedures 24-4

CALIBRATION AND CORRELATION

As with any other measurement skid resistance measurements are of limited value, or may even be totally useless, unless the measuring system performs its functions in such a manner that the obtained data falls within acceptable limits of accuracy and precision. To assure that this is the case the system must be calibrated periodically.

Because skid resistance is a performance measure, that is, the force required to drag a specified tire over a wetted pavement under specified conditions, no absolute standard exists to which the measured values may be compared or related. Therefore, in the past, correlation studies were conducted in which the results obtained with different skid resistance testers were compared with each other. As part of these correlation activities, and through separate investigations, enough was learned about the characteristics of the features of different testers and the influence of various components and operating conditions and methods on measured skid resistance values to permit significant improvements in the accuracy and precision of skid resistance measurements.

Any measurement process has degrees of precision and accuracy. The term precision refers to the degree of agreement between repeat measurements, while accuracy refers to the degree of agreement of such measurements with an accepted reference level. When correlating different skid testers with each other the mean of all results by all testers has been used as a reference level.

Discuss precision and accuracy

This is not very satisfactory because in all correlation studies the differences between the measurements by several testers under presumably identical conditions has been found to be statistically significant. This means that systematic errors were much larger than random ones. Placement in the wheel track is an example of a random error source while the method of applying the water in front of the test tire is an example of a systematic error.

Discuss systematic and random errors. See Teaching Aid 2401

Knowledge about the error sources has been used to upgrade the ASTM E 274 Standard Test Method (36), in particular by specifying the limits within which tester components and instruments must perform. These limits are compromises between what is permissible and what is practical. It is incumbent on every tester operator to periodically calibrate his tester to assure that it conforms to the requirements of ASTM E 274.

Some of the systematic errors would be eliminated if all testers were of identical design. This is not the case. ASTM Method E 274 does not specify tester design details except with respect to the "pavement wetting system," that is, the water nozzle and its position with respect to the test tire. The same is true about Mu-meters, where ASTM E 670 only specifies the tire and the wetting systems and all other vehicle and measurement systems are defined only by acceptable parameters of performance.

Problems with performance specifications of ASTM 274

Field Test and Calibration Centers

To aid users of skid resistance testers and to assure that reported Skid Numbers relate to a common basis, Field Test and Evaluation Centers have been established at:

- Texas Transportation Institute,
  College Station, Texas
- Ohio State University
  East Liberty, Ohio

At these centers testers are calibrated and operating personnel instructed in proper test procedures.

Because calibration of an individual tester against some reference is necessary and the use of the means of the results from testers participating in any given correlation study does not provide a fixed reference, the centers calibrate a user's tester against a standard tester. The latter in turn is calibrated against a single primary reference tester maintained by the National Bureau of Standards. The primary and secondary reference testers are used only for calibration runs and directly related work.

Calibration methodology

For the calibration runs "standard surfaces" are used. These standard surfaces are designed, built and used for tester calibration only. They span the range of skid resistance values that are likely to be encountered in field work. The surfaces are subject to similar skid resistance variations from use and weather as highway pavements are. Therefore it is not possible to calibrate a tester directly on them by running a series of skid tests and making appropriate adjustments until the mean of the measured values agrees with the skid resistance of the standard tests surface. Instead, correlation tests with the secondary reference tester are made.

CALIBRATION PROCEDURES

There is no way of predicting how long a tester will stay in calibration. For practical and economical reasons it can be taken to a Field Test and Evaluation Center only occasionally. Once every two years has been recommended. It is therefore necessary for the user to recalibrate and maintain his tester between visits to the national center. The permissible tolerances are given in ASTM Method E 274 and in the manufacturer's manual for the tester. A further guide is the settings that were made at the Field Test Center to bring the measured skid resistance value into agreement with those of the secondary reference tester.

As a minimum, the following items require attention:

- Speed Measurement - Because on common pavements skid resistance is a strong function of speed, it is essential that test speeds are accurately measured.
- Water Application - This involves proper functioning of the water nozzle and its correct positioning. In addition, the discharge rate must be within specifications. V 2401
- Wheel Load - As long as no changes have been made on the trailer it may be assumed that the wheel load remains unchanged. On testers that have a two-component hub that measures both the horizontal and vertical force to compute instantaneous skid resistance during a test, the vertical force measuring system should be calibrated every time the horizontal one is checked.

  A word of caution: Force calibrations are by necessity made statically. They therefore do not include effects due to aerodynamic loading or unloading of the trailer wheel. Thus, the addition or removal of a sign on the trailer may change the

BEST DOCUMENT AVAILABLE

actual wheel load significantly during high-speed tests even though the static load has changed little.

- Skid Resistance - There are two methods; one consists in applying a known torque to the test wheel hub, the other in applying a measured friction force to the tire. The former is known as the torque arm calibration, the latter as the force plate method.

  Calibration by means of a force plate is the preferred method because it includes the test tire. It should be made in accordance with ASTM Method E 556.(36)

  If a force plate is not available the torque arm calibration may be used. If a tester has a system that measures test wheel torque instead of horizontal force the double calibration method will not automatically give comparable results because on the force plate the measured torque is increased by the shifting of the tire contact patch as the horizontal force is increased. Because this is a systematic difference it can be corrected if the radial stiffness of the test tire is considered constant. It is, however, one more reason why the force plate calibration method is preferable since it more closely duplicates conditions in the field than does the torque arm method. (37)

  If a calibration differs from that obtained at a Field Test Center, the measurement system components should be calibrated individually and/or needed repairs made as required. Previous calibrations, especially those at a Field Test Center, and ASTM 274 are guides to correct component performance.

- Test Tires - Although test tires in the past have shown remarkable uniformity this cannot automatically be assumed to be true, expecially if a tire has been stored or has seen considerable use. Therefore, frequent calibrations by means of the force plate are desirable to guard against errors. The run-in and conditioning procedures prescribed by ASTM E 501 should be followed meticulously. Because inflation pressure is an important variable it should be measured with a calibrated gage.

- General - In connenction with a calibration all components and functions that can in any way affect the validity of the measured skid resistance values should be checked and corrected as needed. This may include the cycle timer(s), brake system performance, and wheel balance.

During a calibration at the Field Test and Evaluation Center, operators will learn which components of their tester require monitoring. For a detailed discussion of all possible factors that may affect correlation and how variables can be controlled by calibration see NCHRP Report 151.(38)

Note, however, that this report was prepared before the former ASTM Standard Test Tire was replaced by the E 501 Tire and prior to the revision of Method E 274 and adoption of E 556. Therefore some of the numerical values cited in this report are no longer applicable and some of its recommendations have not been adopted or were modified.

Routine Procedures

All calibration results should be carefully identified, recorded and presented. Such records can be invaluable aids in identifying the source of future malfunctions, the existence of drift, and when the validity of field data should be questioned.

When a tester operates out of a single base it is advantageous to select a road segment on which to make several check tests as the tester leaves for work in the field. Such tests will show if there are any gross malfunctions, even if there are variations from day to day due to the variability of the pavement. The check section should be far enough away from where the tester is garaged to insure that the test tire has been warmed up as required by ASTM E 274.

Such tests are not a substitute for calibration, but they can indicate the need for calibration, especially if a component has failed or has seriously gone out of calibration. Checks of this type (and good record keeping) can prevent subjecting the validity of large amounts of data to doubt when eventually a tester malfunction is discovered. The checks can also help to establish the frequency and type of calibrations that should be performed.

Practical daily checks.

If the tester has temperature indicators these should be kept in calibration. At present it is not feasible to correct skid resistance values for temperature, but this may change as more knowledge concerning the seasonal and short term variations of skid resistance is refined. For certain purposes it may turn out to be extremely valuable to be able to correct historical data for temperature effects.

Operating Procedures

Operating and data evaluation procedures must also conform to certain limits or standards. ASTM Method E 274 provides some guidance, but to a large extend operator performance is a matter of skill, experience and understanding of the skid resistance measuring process. Participation in a calibration at a Field Test Center will provide the attending operators with valuable training, but new operators should, after appropriate instruction, be compared to veterans to ensure that the results they obtain in both calibration and field tests are accurate within the same limits as those obtained by the personnel they replace.

2401

CALIBRATION PROCEDURES

- Speed Measurement
- Water Application
- Wheel Load
- Measurement of Friction Resistance
- Tires
- Others

SESSION 31

INSTRUCTORS GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraph Transparancies V 3101-V 3110

The importance of high quality construction materials should be strongly emphasized.

Emphasize that what normally determines whether materials will be good for highway building is their origin,

It should also be pointed out that material sources can be mapped for future use and that geological mapping can to some degree indicate the cost of building a road.

Texturing or crushing of the rock into aggregate is very important in producing skid resistant pavements..

Synthetic aggregates should be discussed.

With this brief beginning, lead into Session 31 of the Participant Notebook.

SESSION GUIDE

SESSION: 31. FACTORS AFFECTING SKID RESISTANCE MATERIALS

SESSION OBJECTIVES:

The importance of paving materials in providing high skid resistance cannot be overemphasized. Participants will learn to identify characteristics of materials that should be used in pavement design to achieve high skid resistant pavements, and those materials that should be avoided because they are polish susceptible.

REFERENCES: 4, 7, 39, 40

CONTENT:

Importance of Paving Materials in Skid Resistance 31-2

Origin, Type and Characteristrics of Aggregates 31-3

Texture 31-6

Resistance to Polish 31-8

Future Propects for Road Aggregates 31-9

IMPORTANCE OF PAVING MATERIALS IN SKID RESISTANCE

There are a great variety of materials available throughout the country for use in roadway paving. Unfortunately, due to inherent characterisitics, many of these materials will not provide an acceptable level of skid resistance and maintain this level for the life of the pavement surface. Since a high level of skid resistance often may be the decisive factor in avoiding a wet accident, the continued search for abundent high quality materials continues. In addition, the preparation of these materials for inclusion in the paving mix is of utmost importance. Should inadequate materials be included into pavements they may be slippery at time of construction or become so shortly there-after opening the way for accidents, human misery and legal liability of the operating authority.

Present a broad overview of the rock types through out the United States and give examples of how this has affected the types of roads build, i.e. Bituminous versus pcc.

In order to develop this section it is necessary to define basic terminology. These terms are:

Igneous Rock

Rock formed by the cooling and solidification of molten liquid material. Originally the earth was completely composed of this type of rock.

Metamorphic Rock

Rock formed by the recrystallization of other materials by heat, pressure, chemical change, or by a combination of these.

Sedimentary Rock

Rock formed from the products of weathering regardless of whether by water, wind, glaciers, etc. Originally named after rocks laid down by water, hence the name sedimentary.

Texture

This term is usually broken into microtexture and macrotexture and applied to both rocks (aggregates) and pavement surfaces. To define these terms in a general way - macrotexture may be referred to as the large or rough texture and the microtexture as the fine texture. Texture is important to the skid resistance of a pavement surface.

Aggregate

For this course any hard inert material used for mixing with a cementing material to form the load carrying portion of a roadway.

Weathering

The geological process by which a rock is broken down into smaller particles by the environment. Some of the weathering agents are water, wind, chemical, mechanical, etc.

ORIGIN, TYPE AND CHARACTERISTICS OF AGGREGATES

Origin

All rocks may be divided into three categories:

- Igneous
- Sedimentary
- Metamorphic

A thorough coverage of this session is essential. In this part of the lecture use viewgraphs 3101, 3102, 3103, and 3104.

Igneous Rock - In most cases igneous rocks make the best crushed aggregates to use in surfaces for skid resistance purposes. Originally the earth consisted entirely of this type of rock which was formed from molten magma. Igneous rocks make good roadstone because they generally contain silica, feldspar, the heavy minerals, hornblende, etc., and are very hard and well cemented. They are rather common in the Appalachian Mountains, the Black Hills and the Ozark Mountains. There are relatively few igneous rocks outcrops in the Great Plains and the Mississippi Valley.(39) Common igneous rocks are:

- Granite
- Diabase (Trap Rock)
- Basalt
- Diorite
- Graywacke
- Aplite

Sedimentary Rock - These rocks are formed by cementation of particles from other rock, brough about by chemical and physical weathering. Representative types of sedimentary rocks are:

- Limestone
- Sandstone
- Shale
- Siltstone
- Conglomerate

Metamorphic Rock - Are those rocks that have undergone change. They have been recrystallized by heat or pressure or both. Examples of this type of rock are:

- Marble
- Gneiss
- Slate
- Quartzite
- Schist
- Greenstone

The importance of being knowledgeable about different types of aggregates (rocks) is that it enables the personnel with responsibilities in the skid field to:

Discuss the reasons for being knowledgeable about aggregates.

- Identify aggregate sources with high skid resistance potential.
- Be on the alert for slippery pavements known to contain poor aggregates.
- Advise pavement design personnel about potential aggregate problems as far as skid resistance is concerned.

Because aggregates comprise more than 90 percent of a pavement mixture, the desirability of selecting wear and polish-resistant aggregates for pavement surfaces is very important.

The most important aggregate property for wear resistance is mineral hardness. To resist wear, an aggregate must be composed of hard, strongly bonded, interlocking mineral grains such as, for example, most quartzites and diabases. To resist polishing under heavy traffic, an aggregate must be composed of a high proportion (50 to 70 percent) of hard mineral crystals (Mohs hardness >5) embedded in a matrix of softer minerals such as sandstone, ardose, and other gritty aggregates. However, the mineral grains must be strongly bonded so that nondetrimental, slow differential wear will occur.

Discuss the importance of mineral hardness in aggregates using viewgraph 3105.

Alternatively the aggregate must be composed of all, or almost all, hard crystals well bonded in a porous configuration. The pores replace the softer matrix and allow irregular fracture and slow wear to occur. This process results in the maintenance of high friction without unduly rapid wear. Examples of aggregates in this group include calcined bauxite and some expanded slags, shales, and slates.

Other characteristics that result in initial desirable surface textures and assist in maintaining them over the expected life of the surface include particle shape, size, and gradation. Bulky, angular particles obviously provide macrotextures that are superior to those that result from the use of flaky, rounded particles. This involves laboratory evaluation of aggregates and pavement specimens, with the objective of predicting polish-resistance and skid resistance performance. Laboratory methods found to be useful include circular track devices that simulate field conditions, determination of polished stone value(PSU), and petrographic studies.

A number of states have experimental programs to determine polish values. In a Texas study it was generally found that all pavement section had high initial skid resistance values. The trend was for the skid resistance to drop very rapidly during the first 50,000 wheel passes, continue to reduce at a moderate rate through 1,000,000 wheel passes and from then continue to reduce at a slow rate through 7,000,000 wheel passes. There did not appear to be a terminal polish level. The skid resistance of the pavement sections was consistent with the polish value of the aggregates used.(7)

Using viewgraph 3106 desirable aggregate characteristic should be thoroughly discussed.

Four characteristics should be evaluated in the selection of aggregates for skid resistant surfaces. These are:

- Texture,
- Shape,
- Size,
- Resistance to wear and polish.

General - Characteristics such as texture, mineral constituents, chemical composition and certain physical properties are controllable through aggregate source selection.

Further characteristics such as shape (angularity), particle size, range of sizes and gradation may be produced by processing, and also controlled through aggregate source selection.

TEXTURE

Microtexture

Microtexture or roughness of aggregate is a very important characteristic contributing to adequate skid resistance of pavements.

- For PCC pavements microtexture refers to fine-scale roughness contributed by individual small asperities of the fine aggregate particles in the mortar.
- This would also be true for surface treatments with fine aggregate, seal coats (sand seals and screenings) and asphalt slurry seals.
- In asphaltic concrete and larger aggregate seal coats, the microtexture of the coarse aggregate sizes is the most important characteristic.
- Microtexture of an aggregate particle must be specified or determined before being used in pavement mixtures; but of greater importance is the change in texture during its service life.
- Minerals of varying hardness in the aggregate matrix may wear differentially under traffic resulting in a continually renewed non-polished surface.

In this section aggregate texture should be explained. Use viewgraph 3107. Stress how microtexture and macrotexture combine to produce skid resistance.

Referral back to adhesion and hysteresis will strengthen those concepts as well as aiding understanding of texture.

- On the other hand, if the cementing matrix is strong, the individual grains will be tightly held and polished by traffic.

- The rate of polish depends on the hardness of the grains, frequency of contact with traffic and the kind of abrasive material used as the polishing medium on the surface.

Macrotexture

The macrotexture or coarse texture is the predominant texture contributing to skid resistance of bituminous pavements above 30 mph(48 kph).

- Shape and size of the individual aggregates are important variables controlling skid resistance.(4)

- The angularity of coarse aggregates contributes to tire-pavement friction in the case of asphalt concrete and aggregate seal coats by establishing points of contact with the tire rubber that protrude above the water level.

- Angularity is most readily attained by rock crushing operations.

- Aggregates of different mineral composition with the same angularity may wear or polish at very different rates.

- A potentially slippery situation may develop if rapid wear and polish reduces the angularity of the points in contact with the tire.

- Aggregate size is controlled by grading requirements.

In the case of screenings for seal coats, aggregate size is a very important consideration in the completion of surface requirements in terms of angular projections to different heights so as to provide rubber envelopment and drainage patterns.

In the case of asphaltic concrete, size is important in creating the character of surface exposed. Variance in maximum aggregate source may result in different changes in tire pavement friction under equivalent traffic exposure.

RESISTANCE TO POLISH

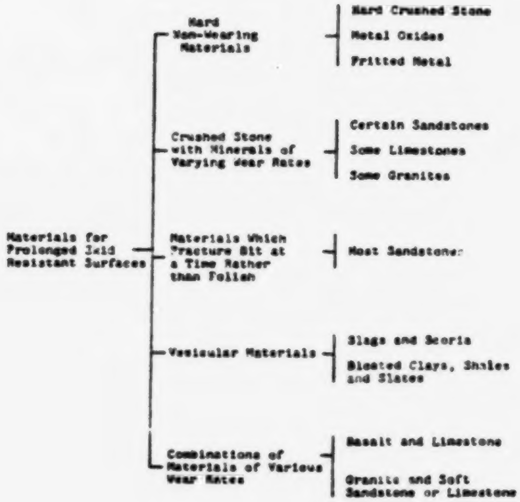
Having chosen an aggregate of appropriate microtexture and angularity and a proper maximum size and gradation, it then must be determined if such a combination will produce the desired tire-pavement friction and maintain the necessary skid resistance during the service life of the pavement.

Resistance to polish is very important and needs to be stressed. In conjunction with viewgraph 3108 and 3109.

Surface microtexture renewal processes may be aided by proper selection of aggregates forming the structural load carrying capacity of the mix. The choices that may be available include granulated materials such as sandstone; uniformly dispersed small sharp particles (quartx in a limestone matrix); certain iron ore gravels and vesicular materials such as selected slags, scorais, or manufactured aggregates of the lightweight type such as expanded clays, shales and slates. Table 31-1 illustrates materials for skid resistant surfaces.

TABLE 31-1

MATERIALS FOR SKID RESISTANT SURFACES (4)


Materials for Prolonged Skid Resistant Surfaces
Hard Non-Wearing Materials
Hard Crushed Stone
Metal Oxides
Fritted Metal
Crushed Stone with Minerals of Varying Wear Rates
Certain Sandstones
Some Limestones
Some Granites
Materials Which Fracture Bit at a Time Rather than Polish
Most Sandstones
Vesicular Materials
Slags and Scoria
Bloated Clays, Shales and Slates
Combinations of Materials of Various Wear Rates
Basalt and Limestone
Granite and Soft Sandstone or Limestone

Polish Susceptibility

Certain aggregates are very susceptible to polish. These must be identified and avoided for use in pavement surfaces. It is possible to use polish susceptible aggregates by careful blending with polish resistant aggregates and careful quality control of size and maintain proper friction values.

Polish susceptible aggregates should be discussed in the framework of what to avoid in the selection of aggregates. Give examples of polish susceptible aggregates.

Limestone - Most limestones are very susceptible to polish and since they are abundent in the United States this presents a difficult problem. It is difficult or costly to avoid their use. Some limestone aggregates polish very rapidly and lead to low tire-pavement friction values in a relatively short period.(4) The calcareous aggregates such as arch marble that are sometimes used as polish resistant aggregates contain impurities such as quartz intrusions that give the polish resistant qualities.

Other Polish Susceptible Rocks - Aggregates derived from serpetinite, soapstone, siltstone, shale, schists, etc., may polish very rapidly. From experience engineers know these rocks are not best suited to provide long lasting skid resistant surfaces. Occasionally a pavement mix design will contain aggregates from one of these rocks despite efforts to avoid them. When reviewing pavement data prior to skid testing a watchful eye should be kept for known polish susceptible aggregates. Upon discovery of such aggregates this should serve to alert the engineer that a potential problem exists.

FUTURE PROSPECTS FOR ROAD AGGREGATES

There has become in many places an acute shortage of quality aggregates for road building. This situation has come about for a number of reasons, such as a large number of good sources being depleted, the building and construction industry making heavier demands, zoning laws that restrict quarrying, environmental restraints, etc. These reasons, coupled with the fact that there have always been large areas in the United States where quality materials for aggregates do not exist, point toward a challenging future in provident acceptable aggregates.

Lead into this section by explaining the reports for the shortage of aggregates for road building using viewgraph 3110 and finish section with review of synthetic aggregates.

Recycling of aggregated and pavement material when existing pavements are being replaced or rehabilitated is receiving much attention at present. The economic benefits of this are obvious, and the demand on new aggregate sources is reduced.

A number of things have already been attempted to alleviate the aggregate situation. One of these is the production of synthetic aggregates for skid resistant surface courses. Synthetic aggregates are produced by the thermal or chemical processing of natural or manmade materials. The physical properties of these aggregates vary considerably, depending on raw material and method of processing, and their properties are often considerably different from those of the natural aggregates on which current test methods and specifications are based.

In one report, potential sources of synthetic aggregates are reviewed with respect to existing technology, and the aggregates are differentiated as to aggregates that are "tailor-made" such as skid-resistant aggregates and those that are "non-tailor-made," such as lightweight aggregates, slags, and industrial by-products.(40) Table 31-2 lists ceramic processes that are potentially useful in the manufacture of paving aggregates.

With the exception of some form of thermal-chemical processing, the potential techniques for processing ceramic aggregates are energy intensive and will become more expensive as energy becomes more costly. Exact energy requirements depend on the chemical composition, of the raw material, the processing method, and the number of processing steps required.

Other than lightweight aggregates from shale and clay, there are almost no examples of manufactured synthetic aggregates that are used as skid-resistant aggregates in significant quantities. Blast-furnace slag is an industrial by-product widely used as an aggregate, but neither it not ordinary lightweight aggregate is produced specifically for skid-resistant purposes. There have been few significant additions to the list of available or potentially available synthetic aggregates in the last decade and a half. Increased energy costs and environmental restrictions and the shortage of money for capital expenditures have placed additional constraints on the development of synthetic aggregates.

TABLE 31-2

POTENTIAL SOURCES OF SYNTHETIC AGGREGATE BY METHOD OF MANUFACTURE. (39)

Process	Description	Example	Current Pavement Use	Comments
Sintering	Heating (to below melting point) of agglomerate fines into larger, tougher particles	Brick making; sintered shales, clays; molochite, refractories; fly-ash lightweight aggregate	Texas ("Red Rock")	Agglomerate fine material (e.g., wastes, clays) into hard, large-sized particles; blend ingredients to control differential hardness; properties vary
Sintering with bloating	Heating as in sintering, but bloating gives "expanded" particle	Expanded shale, clay, coal-mine refuse	Expanded shale, clay, coal-mine refuse	Good skid resistance, doubtful durability and wear resistance; control of wear and skid resistance by bubble size, density, and wall thickness
Glass ceramics	Controlled thermal processing of glass to give appreciable crystal growth	Processed blast-furnace slag; Synopal	Extensive use; blast-furnace slag; excellent skid resistance	Development of crystalline phase controlled by processing and composition; desired process waste slags
Glass ceramics with bloating or expansion	Melted glass expanded by internal gas or injected air or steam; appreciable crystal growth on cooling	Expanded blast-furnace slag	May not be advantageous in cost if glass-ceramics process gives adequate differential wear	Expanded blast-furnace slag currently used in block manufacture; no advantage reported over normal blast-furnace slag; cost and environmental disadvantages
Calcining	Heating in solid phase to effect crystal change and drive off water or carbon dioxide	Calcined bauxite	Limited because of expense	Potential as "high-class" material; cost-effectiveness needs to be improved
Chemical processing	Hydraulic cement or other chemical reaction at ambient temperature	Pozzopac, sulfate-fly-ash waste	None	Questionable; low energy input implies material without hardness and wear resistance
Thermochemical processing	Hydraulic cement or other chemical reaction at elevated temperature	None known	None	Inclusion of hard particles in softer matrix suggested; process represents low-energy agglomeration of fines
Glassmaking	Heating to above melting temperature; rapid cooling without crystal growth	Water-quenched boiler slag, steel and blast-furnace slags, slags from incinerators, etc.	Boiler slag; controversial for skid resistance	Marginal as skid-resistant aggregates; modify to glass-ceramics process if possible; vesicularity may extend usefulness
Glassmaking with bloating	Melted slag expanded with gasses produced in process or with injected air or steam; no appreciable crystal growth on cooling	None	None	Vesicularity may improve skid resistance; probably not preferred process but may be necessary with some waste-slag compositions that do not readily crystallize
Recycling	Recycling of portland cement concrete or asphaltic pavements	None	None; ongoing demonstration projects	Alteration of future construction to allow aggregate recycling should be considered; crushed portland cement concrete may give good differential wear
Coatings	Thermally or chemically applied thin surface coatings	None known	None	Limited application unless coating is thick as in composite material, expensive processing

Some tailor-made ceramic aggregates made specifically for use as skid-resistant aggregates, but little used in the United States are processed synopal and calcined bauxite.

There are a number of potential non-tailor-made sources of skid-resistant aggregates. In some cases, these materials have been used as aggregates (blast-furnace slag or lightweight aggregates). In other cases they are yet to be developed as aggregate sources (Taconite tailing, steel slags, and pyrolysis slag).

Some potential by-product aggregate sources for skid resistant mixtures are:

- Lightweight aggregate from shale and clay.

- Lightweight aggregates produced by sintering fly ash and by sintering refuse from coal-preparation plants.
- Blast-furnace and steel-furnace slags.
- Industrial and mining wastes.

3101

TYPES OF ROCK

- Igneous
- Sedimentary
- Metamorphic

3102

EXAMPLES
OF
IGNEOUS ROCK

- Granite
- Diabase
- Basalt
- Diorite
- Aplite

3103

EXAMPLES
OF
SEDIMENTARY ROCK

- Limestone
- Sandstone
- Shales
- Siltstone
- Conglomerate

3104

EXAMPLES
OF
METAMORPHIC ROCK

- Marble
- Gneiss
- Slate
- Quartzite
- Schist
- Greenstone

3105

MOH'S SCALE OF HARDNESS

1. **Talc**
2. **Gypsum**
3. **Calcite**
4. **Flourite**
5. **Apatite**
6. **Feldspar**
7. **Quartz**
8. **Topaz**
9. **Corundum**
10. **Diamond**

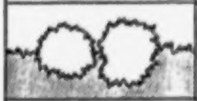
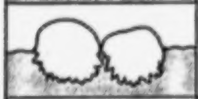
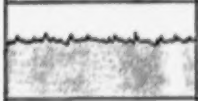
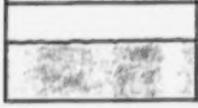
3106

AGGREGATE CHARACTERISTICS

- **Texture**
- **Shape**
- **Size**
- **Resistance to Wear and Polish**

3107

SCALE OF TEXTURE

SURFACE	MACRO (large)	MICRO (fine)
	rough	harsh
	rough	polished
	smooth	harsh
	smooth	polished

3108

SKID RESISTANT SURFACE MATERIALS

Hard Non-Wearing
- **Hard Crushed Stone**
- **Metal Oxides**
- **Fritted Metal**

Crushed Stone Varying Wear
- **Certain Sandstone**
- **Some Limestone**
- **Some Granite**

3109

SKID RESISTANT SURFACE MATERIALS

Fracture rather than Polish	Sandstone
Vesicular Materials	Slags/Scoria Bloated Clays Shales/Slates
Combinations, Varying Wear	Basalt/Limestone Granite/ Soft Sandstone or Limestone

3110

REASONS FOR SHORTAGE OF AGGREGATES FOR ROAD BUILDING

- Sources Being Depleted
- Heavier Demands from the Building and Construction Industry
- Zoning Laws that Restrict Quarrying
- Environmental Constraints

SESSION 32

INSTRUCTORS GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraph Transparencies V 3201-V 3208

This session should be a continuation of Session 31 and as such should clarify and be an extension of the previous section.

If unsuitable materials are used in pavement design the obvious result is a failure of some type.

In addition to skid resistance problems that may be brought on by materials there are others dealing with the pavement. Most often the problems stem from a design deficiency of one type or another. There are, however, problems that may develop from poor construction methods.

Pickup in the Participant Notebook.

BEST DOCUMENT AVAILABLE

SESSION GUIDE

SESSION: 32. FACTORS AFFECTING SKID RESISTANCE - PAVEMENT

SESSION OBJECTIVES:

During this session participants will develop an understanding of how pavement characteristics affect skid resistance. Specifically the causes of reduction in pavement skid resistance and the effect of pavement drainage on skid resistance will be detailed.

REFERENCES: 41, 42, 43, 44, 45

CONTENT:

Causes of Reduction in Pavement Skid Resistance 32-2

Wear and the Loss of Skid Resistance 32-5

Effects of Studded Tires Used on Highways - Federal Highway Administration, July 1974 32-14

The Effects of Surface Drainage on Skid Resistance 32-16

CAUSES OF REDUCTION IN PAVEMENT SKID RESISTANCE

Pavements, as is the case with all other elements in a road system, show wear and deterioration over time and under traffic conditions. This is a natural evolution and is to be expected. On high volume bituminous pavements, resurfacing is usually programmed on a cyclic basis. If pavements retained their as-built qualities until resurfacing became necessary many associated problems would be simplified. However, this is not the case since there is a gradual wearing and weathering away of the pavement surface. As deterioration occurs, one of the results is that ingredients in the surface mix begin to polish regardless of the materials used. The materials, of course, dictate the rate of polish. Strictly speaking, it is incorrect to refer to any aggregate or material as being non-polishing.

General discussion of how pavements show wear and deterioration

In general, the texture of a pavement is at its best level when new or after an initial traffic break-in period. Continous use by traffic tends to result in a gradual deterioration in the broad categories of polishing or reduction in microtexture and wearing away of macrotexture. In asphaltic concrete the coarse aggregate is primarily subjected to polishing, whereas the fine aggregate and the mortar of portland cement concrete usually becomes polished or worn away. The result is a reduction in skid resistance, particularly in the wheelpaths, and consequently deterioration in wet-weather performance.

Short discussion on why pavements have best skid resistance after break-in period

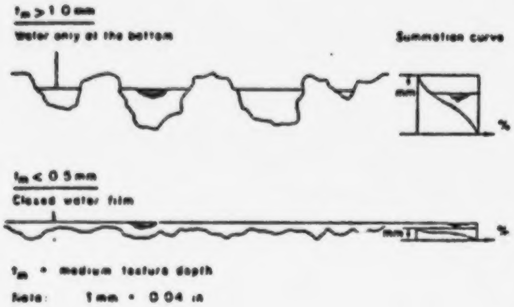
Micro and macrotexture of pavements are closely related to the micro and macrotexture of aggregates. The microtexture is chiefly connected with the friction force developed for both dry and wet pavements. In wet conditions the microtexture breaks through the last thin waterfilm in the contact zone between the tire and road. The macrotexture makes it possible, to squeeze out the water lying on the road surface quickly. This is important at high speeds since the tire tread pattern alone is not sufficient. Macrotexture, on the other hand, reduces the waterfilm on the surface.(41)

Discuss microtexture and macrotexture of pavements using viewgraph 3201 as an example - stress that the microtexture breaks through the last thin film in the tire contact zone

For the same rainfall intensity (light to medium) the water level lies below the pavement-tire contact for a rough pavement, while for a pavement with smooth texture, a closed waterfilm exists. This is shown in Figure 32-1.

FIGURE 32-1

WATER LEVEL ON DIFFERENT SURFACES


$t_m > 1.0$ mm
Water only at the bottom
Summation curve
1 mm
%
$t_m < 0.5$ mm
Closed water film
mm
%
t_m = medium texture depth
Note: 1mm = 0.04 in

A closed waterfilm is detrimental to sight distance through redirection of light and water spray. A good macrotexture can make a significant contribution to the improvement of otherwise insufficient drainage conditions, for example: due to a relatively flat cross slope.

Skid number is a function of surface texture. A surface that has good microtexture ensures a high skid number at low speeds. Macrotexture becomes more important as speed increases. The combined effects of macrotexture and microtexture interact to provide adequate skid resistance at high speeds.(42)

As traffic rolls over a pavement various things happen. The pavement is compressed, and unless it fully rebounds it will rut and eventually fail. In flexible pavements aggregate particles can become dislocated or reoriented and binder material can migrate to the surface. These effects are more prevalent on roads that carry heavier vehicles then those that do not.

The tires scrub and squirm. Even when a tire merely rolls, at least some of the tread elements in the contact patch move relative to the pavement surface. This occurs only after the prevailing local friction has been overcome: shear forces develop in the contact patch and they can dislocate particles or at least help to reorient them. Once a tread element moves it tends to cause abrasion and changes in the surface characteristics of the aggregate particles. These phenomena are amplified when torque is applied to the tire, whether it is to maintain constant speed, or to accelerate and decelerate.

These are complex phenomena, all interacting with one another. Moreover, they have recently been further complicated by the widespread use of studded tires. Such tires add another component that is destructive to road surfaces: as a stud is moved into contact by the tire it impacts on the surface with considerable speed and force. Tread elements demonstrate this quality as well, but because they are resilient this is not a serious problem. However, tread design contributes to the noise that tires generate.

It is important to keep in mind that the lasting effects that traffic can have on a pavement fall into three broad categories:

- Changes in the surface structure,
- Wear, and
- Polishing.

Explain the lasting effects that traffic has on pavement use viewgraph 3202, effects of traffic on pavement

The first of these categories does not involve loss of material but includes the reorientation of aggregate particles, binder migration, etc. The second category comprises everything that involves permanent loss of material. The third category refers to changes in the surface microtexture, principally of the aggregate particles.

Define polishing

Polishing does not, by definition, involve loss of material but refers only to the smoothing of a surface. This could be the result of plastic flow of the material being polished, but mechanisms involving loss of material are not excluded; indeed, they are more commonly operative in the case of pavement materials. Wear, on the other hand, refers specifically to the loss of material, however gradual. It is therefore measured as weight or volume lost, decrease in thickness, etc.

The degree of wear indicates nothing about the change in surface smoothness or polishing. Indeed, certain types of wear increase the texture or roughness of a pavement surface.

WEAR AND THE LOSS OF SKID RESISTANCE

Any kind of pavement wear is undesirable, unless accompanied by desirable side effects of sufficient magnitude, because it means that the original surface, whether an overlay, the top course, or the surface layer of any kind of pavement, is being removed or altered. Because wear is seldom uniform, it is primarily a question of whether wear makes a road unserviceable because of the unevenness of the surface or because of the complete disappearance of the surface course.

Carefully differentiate between polish and wear

Wear either can be gradual or it can occur in a step-like fashion (breaking out of aggregate particles, etc.). After asphalt has oxidized and is eroded, the shear stresses between tire and surface may be sufficient to break out particles. This type of attrition is promoted by studded tires and can become catastrophic on surface treatments because the shear forces are augmented by localized impact and other forces. Brittle materials are particularly susceptible to this type of attack.

Explain the mechanism of wear and reasons for different wear rates

Generally, wear is of the gradual, continuous type, at least as far as individual aggregate particles are concerned. This wear is greatly promoted by loose material, whether generated by the pavement itself or blown or brought in from elsewhere. The loose particles serving as abrasives may be the size of fine sand or smaller. After ice and snow are gone, the "antiskid materials" used for ice control may provide, temporarily, much larger particles, but these are usually quickly broken up by traffic or thrown off the pavement. It is largely the fine material that serves as the abrasive.

If the surface aggregate and the filler consist of homogeneous, amorphous stone, wear will be comparatively slow, unless an outside source furnishes more-abrasive material. Skid-resistant aggregates are rarely homogeneous and amorphous. The debris from these will contain particles that are harder than the matrix in which they were originally imbedded. These hard particles help to wear the matrix away, releasing more hard particles to replace those that are ground down and blown off the pavement.

Wear is very much a function of the aggregate characteristics. It is not fully understood in all its ramifications that exist on a highway surface. Attempts have been made to relate aggregate characteristics to probable wear rates, but little success has resulted in generalizing the findings, much less relating them to highway experience.

Stiffler (43) concluded from his research on abrasive wear that road stones wear by scratching and pitting, and that rapidly wearing materials exhibited evidences of both types of attrition, whereas slower wearing ones showed mostly scratching. He established that the hardness of the mineral relative to that of the abrasive is decisive for the rapidity of wear: if the abrasive is harder than the mineral, wear is fast. The wear rates he found correlated well with the hardness of the mineral of the road stones.

However, there were some exceptions. The exceptions were those minerals that showed little pitting. Stiffler found no adequate general model for relating the rate of wear to known properties of the minerals, but he did develop some qualitative relations.

Point out that aggregate wear and pavement wear are not necessarily the same

Aggregate wear is not identical with pavement wear. This is particularly true for portland cement surfaces. The relative hardness of mortar and aggregate can make the wear rate drastically different from what it would be for either mortar or aggregate alone.

From the standpoint of skid resistance, differences in the wear rates of components of surface courses are desirable. This applies equally to rigid and flexible pavements, as well as to all overlays. The different wear rates enhance surface texture, thus providing channels through which water can escape from the contact patch. The surface irregularities also increase the hysteresis component of friction.

Portland cement pavements are given increasingly heavier surface texturing during construction. Wear eventually obliterates this type of texture. Because it is essentially formed in the mortar, the latter must be made hard and wear-resistant if the original finish is not to be lost rapidly.

Wear is promoted by the presence of abrasive material. Obviously, the finer the particles constituting this material, the smoother the resulting wear surface will be; but the wear rate will also be slower. Consequently, for similar materials, slower wear means more polishing, hence lower skid resistance. However, because there is no practical way of controlling the type and quantity of abrasive material on the pavement (except in some instances where foreign material is being brought onto the pavement), there is little that can be done to influence this process, except by judicious design of the surface course.

Polishing

Just as the wear mechanism of aggregates and pavements is still largely a mystery, so is the polishing mechanism. Chiefly this is so because in minerals the two phenomena are not strictly separable. Minerals do not deform plastically to any significant extent and therefore polishing requires the removal of material, though in very small increments.

Explain the mechanism of polishing in relation to the mineral makeup of the material being polished

Polishing is reduction of microtexture. Consequently, it is difficult to measure, further complicating research on its mechanism. The researcher can try to obtain microprofiles, can try to quantify ordinary or stereophotographs of the surfaces, or can use other methods that researchers have employed from time to time. Aside from cost and effort, the chief difficulties are that only very small samples are obtained, and the methods are difficult or impossible to use in the field.

Therefore, one uses low-speed friction measurements instead. The British Portable Tester is employed most frequently. At low speeds the adhesion component of friction is dominant; it is primarily a function of the microtexture of the contacted surface. Such measurements are, of course, made with the surface wetted, but the rubber shoe of the pendulum tester displaces enough water so that the hydrodynamic effects (which influence friction at higher speeds and are controlled by the coarser features of the surface) are practically absent. The rubber responds essentially only to microtexture.

Unfortunately, the results of laboratory experiments on the polishing characteristics of aggregates and pavement specimens are not readily related to the skid resistance as measured on the highway. The latter is obtained and rated at 40 mph, although in the laboratory such speeds cannot be used. This means that the highway measurements contain the effects of macrotexture although those made in the laboratory do not. Thus, the correlation between laboratory and field data is not really good; but, in general, the ranking is about the same, so that laboratory polishing has become a more and more frequently used adjunct to surface course design.

Polishing and wear are not only greatly accelerated by the presence of an abrasive, but the degree of polish depends directly on the size of the abrasive particles. The finer the abrasive is, the lower the friction factor. Although there is usually dust on a roadway, its nature is a matter of conjecture. A major portion of this dust is normally debris of the aggregate. Other material is brought in by the tires, or drops from vehicles, or is blown in from the shoulders and adjoining land.

The effects of such a melange of materials, sizes, and shapes is difficult to assess and cannot be duplicated in the laboratory. Hence, for laboratory experiments arbitrary selections of polishing agents are made. These usually consist of fine gradations of materials much harder than any pavement components, if only because hard powders accelerate the polishing process.

On the road, most of the polishing probably takes place while the pavement is dry because pavements are dry most of the time. In laboratory experiments, polishing is frequently being done wet, partially to eliminate the dust nuisance, but more importantly to cool the rubber pad or tire so as to prevent the rubber from smearing. If the interface were not cooled by water, much lower polishing rates would have to be employed and this would defeat the objective of accelerating the process compared with that taking place in the field. It is, of course, the number of passes, whether of a pad or a tire, that determines the polishing rate.

Note: Most polishing occurs while pavements are dry

There has as yet not been any standardization in laboratory polishing procedures. A review of various methods in use is given by Goodwin (44). No one method has proven itself to be clearly superior to others. It may well turn out that the simplest method is the most practical and useful one. The simplest method for aggregate polishing is clearly tumbling in a jar mill, although it is still necessary to mount the tumbled stones in an epoxy matrix for determining their friction characteristics.

However, full confidence in the validity of all laboratory methods is missing, particularly when relatively small differences in the resistance to polishing are important, as when specifications or standards are to be met. The difficulty lies in the fact that in the field skid resistance is highly variable. It is therefore difficult to accurately determine what the equilibrium skid resistance of a pavement is. The situation is further complicated by the fact that the amount of traffic carried by a pavement plays a part in determining mean equilibrium skid resistance.

Pass over the laboratory polishing methods lightly

Figure 32-2 illustrates this point. It shows the skid resistance of one type of surface course that was installed at the same time in six different locations. The data points were obtained three years after installation. The skid resistance had stabilized at all locations after two years. The daily traffic is the average over the three-year period. Clearly, traffic is the governing factor, not time. Interestingly, the exposure to trucks gives a better correlation than to all vehicles.

Discuss the deterioration of skid resistance with exposure to traffic. Use viewgraph 3203.

The most important surface components in determining the mean microtexture of a pavement are generally the exposed faces of the aggregate particles. The mineralogy and structure of the aggregate determine how easily and how much it polishes. Figure 32-3 shows that aggregate type determines approximately the ranking that a particular type will take with respect to other types. But there can be rather broad ranges for any one aggregate type. For instance, limestones will polish depending on how much siliceous material, and in what size, they contain. Research has shown that any material harder than calcite will improve the skid resistance of limestones. Grain shape, size, and size distribution also play a part in the polishing susceptibility, as do other petrographic properties.

Discuss aggregate polishing in relation to pavements and use viewgraph 3204 as an example

There is still much to learn about how and why aggregates polish; but some generalizations are possible. Dahir and Mullen give this summarization: The highest permanent skid resistance is obtained by aggregates whose sacrificial surfaces are continuously renewed by traffic action. The content of sand-sized, hard particles embedded in a softer matrix has greater beneficial effects on skid resistance than the total amount of "impurities." When mineral composition of an aggregate is uniform, its skid resistance will be higher the more angular and the larger the grain. One might add that vesicular materials can also have good skid resistance even if the material tends to take on a high polish. Hardness is not a virtue in a uniform aggregate, such as quartz pebbles.

FIGURE 32-2

DETERIORATION OF SKID RESISTANCE
WITH EXPOSURE TO TRAFFIC

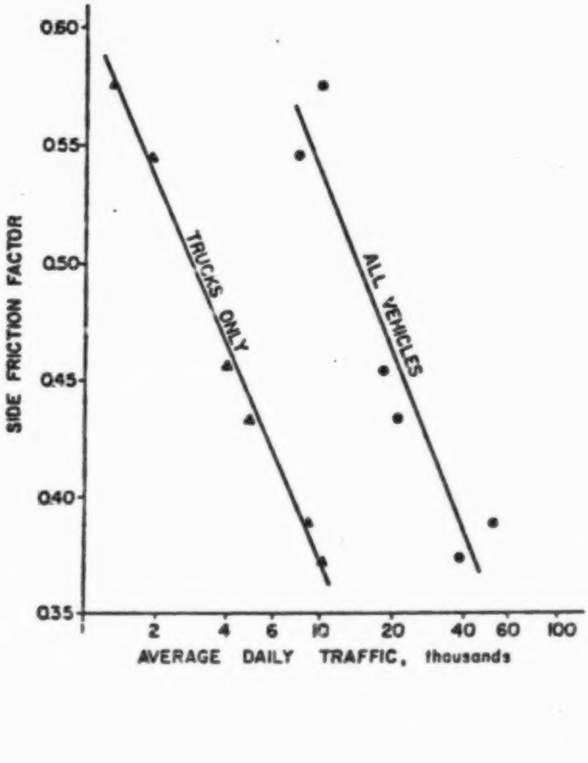
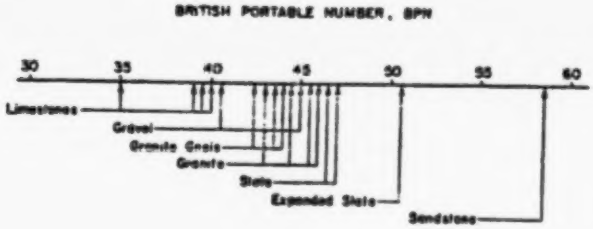


FIGURE 32-3

RANKING OF VARIOUS AGGREGATES
ACCORDING TO FINAL FRICTION FACTOR
AFTER POLISHING IN A LABORATORY MACHINE (45)



The same basic considerations apply to the pavement as a whole, whether it is of bituminous or portland cement concrete. A pavement will retain good microroughness if its irregularities are sand-size and sharp-edged, and if the surface wears fast enough to release the hard particles that form the irregularities before they have worn off or become too well rounded.

Bleeding of Bituminous Pavements

Texture, whether macro or micro, can be lost by covering of the pavement surface with asphalt, as in the case of bleeding on bituminous pavements. With modern asphalt technology and design, "bleeding" has largely been eliminated. However, there are cases in which the equivalent of bleeding can occur. For instance, as a surface treatment wears off, the sealant can give the now exposed original surface a smoothness equivalent to that of a bleeding asphaltic concrete surface.

Most highway personnel are familiar with pavement bleeding and flushing so a superficial coverage should be sufficient.

The pores of vesicular materials or the surfaces of other irregularly shaped materials can be filled in and smoothed by binder material. This most frequently occurs during the manufacture of the mix and explains why some newly placed pavements show an increase in skid resistance over a sometimes fairly long initial period: the asphalt in the pores must be worn away or eroded. In hot weather new asphalt may be deposited in the pores of mixes having a high asphalt and a low surface void content.

Compaction, Rutting, and Particle Loss

Traffic tends to compact bituminous pavements in the wheel tracks. Mix design adequate for the existing or anticipated traffic loads minimizes this effect. However, it is useful to review the consequences of compaction on skid resistance.

Compaction tends to bring more binder material to the pavement surface, and into tire contact. This invariably decreases the overall microtexture of the surface. Compaction also reduces macrotexture; thus, it is detrimental to good skid resistance at all speeds.

This section should be covered thoroughly since compaction, rutting and particle loss are serious problems

In discussing compaction use viewgraph 3205

Another consequence of wheel loads in addition to compaction is mixture flow which permits ruts to form if traffic is strictly channeled. The ruts fill with water and may lead to hydroplaning at lower speeds and increases in splash and spray. This is certainly an added traffic hazard. Ruts can also be formed by excessive wear rates, for which studded tire use is the most likely cause.

For pavements in which compaction occurs, the aggregate particles are not necessarily pushed downward while the binder moves upward. The larger aggregate particles may also be reoriented. This causes the large aggregate faces to become aligned with the surface. If the aggregate is susceptible to polishing, this can lead to rapid decline of skid resistance. Polish-susceptible aggregate can provide acceptable skid resistance on bituminous pavements if the particles are held securely in random orientation. This is particularly true if the aggregate has preferred cleavage planes. The stresses imposed by traffic can produce new fracture faces and therefore expose sharp edges and good texture to traffic. Thus flexibility in surface courses should be held to the minimum dictated by structural considerations.

The various considerations discussed to this point have called for low asphalt content. However, it is important that the content not be so low, especially in coarse-graded mixes, that surface aggregate particles are not firmly anchored. If they are not firmly anchored, they will eventually be torn out. In addition, particle loss is accelerated by studded tires, which may also fracture and split the aggregate particles.

This type of attrition can be very rapid and aids in the formation of ruts. Purely from the skid resistance standpoint such wear is not objectionable because it brings new, unpolished particles to the surface and maintains channels for water escape. However, this does not make the formation of ruts acceptable, if only because whatever is gained in skid resistance in light rain is lost by the lowering of the hydroplaning limit when the ruts fill with water.

Studded Tires

There is no longer any argument that studded tires cause excessive pavement wear. Several states and provinces now prohibit or limit their use.

Numerous investigations have been made into the effectiveness of studded tires. In loose snow and on sanded or cindered surfaces, studs offer no advantage. On ice they are most effective just below the freezing point, with the effectiveness diminishing as the ice temperature lowers. On ice at 32 degrees F, studded tires can reduce stopping distance by about 20 percent for each axle with studs in the tires and, with studs on all four wheels, a curve might be taken safely at 40 mph when without these tires 30 mph is apt to cause spinout. The number of studs per tire does not bring proportional improvement. Above 100 studs per tire very little is gained, but having studded tires on all four wheels is definitely beneficial to vehicle maneuverability particularly in cornering. However, pavement wear is in first approximation proportional to the number of studs which come into contact with the pavement.

Participants find the effects of studded tires interesting. However two things should remembered. Where studded tires are not used, i.e. sunbelt states the subject need not be covered. Secondly, many states are limiting the use of studded tires and they may eventually be outlawed completely.

Since the introduction of studded tires, the damage to pavements has become so great that in August 1974 the Federal Highway Administration issued a policy on studded tires. That policy is as follows:

EFFECTS OF STUDDED TIRES USED ON HIGHWAYS
FEDERAL HIGHWAY ADMINISTRATION, JULY 1974

"Available information indicates that there is no net safety benefit to be derived from the use of present studded tires. This fact, coupled with the excessive wear and physical damage to the roadway surface provides a sound basis for precluding the continued permissive use of a convenience feature which is effective for relatively short periods of time. This warrants State and local consideration of efforts to ban or limit the use of studded tires which cause more pavement wear that normal treaded tires."

In discussing the effects of studded tires use viewgraph 3206 adverse effects of studded tires, 3207 benefits of studded tires, and 3208 conclusion regarding the use of studded tires

The above statement of policy was determined after careful review and analysis of all available reports, studies and other data pertaining to the effects of the use of studded tires on the physical highway and on the traveling public involved. The features of highway safety, driver convenience and pavement deterioration have been under intensive study not only in the United States, but also in Canada and northern European countries. Following are brief statements of the "effects" as found in the total data available.

Reported Adverse Effects of Studded Tires

1. Rutting - Various State studies clearly and conclusively show that studded tires cause significant pavement wear and rutting in the wheel paths.

2. Hydroplaning - Resultant wheel path ruts sufficiently deep to hold water during wet and rainy weather can cause vehicle hydroplaning and subsequent loss of vehicle control.

3. Slippery Pavements - During freezing weather snow plows are unable to remove ice and snow which accumulates in the rutted wheel paths. A hazardous driving condition results.

4. Pavement Markings - Rapid deterioration of pavement markings by wear due to studded tires results in unsafe vehicle operation conditions.

5. Erratic Vehicle Placement - Drivers tend to avoid driving in troughs created by the studded tires. This non-uniform, off

center placement of vehicles in the lane can increase the risk of running off the pavement with a subsequent loss of control or collisions with vehicles traveling in other lanes.

6. Increased Stopping Distances - The use of studded tires increases stopping distances on bare wet concrete pavement.

7. Elimination of Skid Resistant Surfaces - Studded tires cause significant pavement wear eliminating surface textures for skid resistance which have been built into the pavement. Grooves sawed in concrete pavement have been worn completely down in as short a time as 2 to 3 years.

8. Increased Traffic Noise - Studies show increases in traffic noise levels of one and one-half times on stud roughened pavements as compared with normal pavement.

9. Increased Splash and Spray - The ponding of water in the wheel path ruts causes greater wheel splash with a resultant loss of vision and associated hazards.

10. Overdriving - The use of studded tires creates a false sense of security for a driver. The benefit of small braking margins offered by studs in glare ice conditions becomes null when the over-confident driver increases his speed by 5 mph or more. It is also significant that during dry pavement conditions, the driver tends to drive at normal highway speed without considering the reduced traction available to him.

11. Increased Repair Costs - Several highway organizations have estimated 12 million dollars or more in annual repair costs due to studded tire wear in each of their states. It normally is not practical to "fill" the worn ruts, instead the whole lane or pavement must be overlayed. Since the highest wear is associated with the highest traffic volumes, the repair problem is compounded both in difficulty of repair and in an increase in accidents related to repair activities.

Reported Benefits of Studded Tires

1. Decreased Stopping Distance - In glare ice conditions studded tires do decrease the vehicle stopping distance. These glare ice conditions on highways normally occur about one percent of the time in the northern States. Sanding the ice is still the most effective method of reducing stopping distances.

2. Better Steering - Some steering benefits result on ice when studded tires are used on all four wheels. Studded tire use in the United States is nearly exclusively on the rear wheels.

3. Better Traction - Better traction results from the use of studded tires during glare ice conditions, but research shows that reinforced steel chains are even more effective.

4. Convenience - The permanent or fixed feature of studded tires does provide a greater convenience to the driver when compared to the use of chains.

Conclusion

The above analysis indicates that the adverse effects of studded tires both in regard to safety and cost far outweigh the beneficial aspects.

THE EFFECTS OF SURFACE DRAINAGE ON SKID RESISTANCE

Vehicles operating on wet, as compared to dry pavements, experience reduced steering and braking capabilities. Tests have shown that this condition worsens as the vehicle speed increases and that at a critical ground speed the wheel is separated from the pavement by a layer of fluid.

The effects of surface drainage should be discussed thoroughly

Tire hydroplaning is caused by fluid pressures that are developed at the tire-pavement interface. When these pressures become large and the total hydrodynamic force developed on the tire from these pressures equals the total load the tire is carrying, hydroplaning occurs. At this instant, theoretically, the tire loses contact with the pavement and skims over the surface in the same manner that a water skier glides along a water surface.

Hydroplaning causes a loss in the directional stability of a vehicle and can be considerably aggravated if the vehicle is traveling on a curve or is exposed to high cross winds.

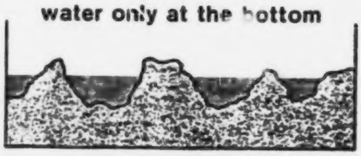
In actuality, complete hydroplaning, even with smooth tires, is probably a rare occurrence. The majority of wet-weather skidding accidents occur as the result of water depths well below those needed for complete hydroplaning.

From research on methods for predicting pavement water depth as a function of rainfall intensity and pavement geometrics TTI concluded that pavement width (drainage length) and cross slope are the primary roadway factors affecting the drainability of a pavement surface. On a two-lane crowned roadway with a cross slope of two percent, a drainage length of 12 ft. (3.65 m), a rainfall intensity of 0.25 in/hr (6.4 mm/hr), the computed maximum water depth would be 0.028 in (0.7 mm). Using the same cross slope and rainfall intensity the computed maximum water depth for a multilane roadway sloped in one direction only, with a drainage length of 34 ft. (10.4 mm) would be 0.046 in. (1.2 mm).

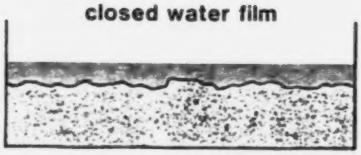
3201

WATER LEVEL
ON
DIFFERENT SURFACES

water only at the bottom



closed water film



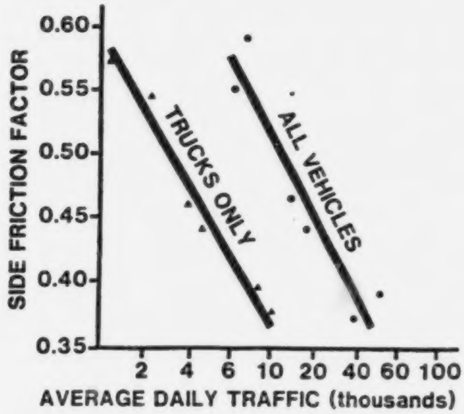
3202

EFFECTS OF TRAFFIC ON PAVEMENT

- **Changes in the Surface Structure**
- **Wear**
- **Polishing**

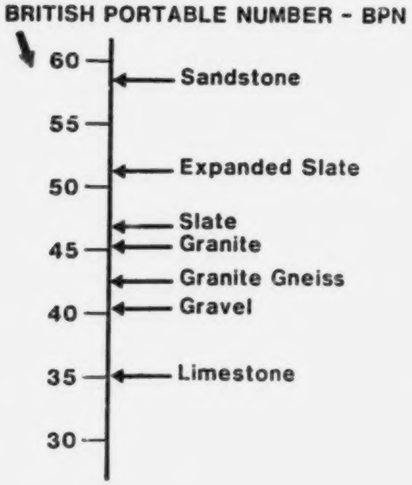
3203

DETERIORATION OF SKID RESISTANCE WITH EXPOSURE TO TRAFFIC



3204

AGGREGATE FINAL FRICTION FACTOR AFTER POLISHING



3205

COMPACTION

- Causes Binder Material to Come to Surface
- Causes Mixture Flow-Rutting
- Causes Aggregates to be Re-oriented

3206

ADVERSE EFFECTS OF STUDDED TIRES

- Rutting
- Hydroplaning
- Slippery Pavements
- Pavement Markings
- Erratic Vehicle Placement
- Increased Stopping Distances
- Elimination of Skid Resistant Surfaces
- Increased Traffic Noise
- Increased Splash and Spray
- Overdriving
- Increased Repair Costs

3207

BENEFITS OF STUDDED TIRES

- Decreased Stopping Distance
- Better Steering
- Better Traction
- Convenience

3208

CONCLUSION:

The Adverse Effects of Studded Tires Both in Regard to Safety and Cost Far Outweigh the Beneficial Aspects.

SESSION 33

INSTRUCTORS GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraphs 3301-3308

APPROACH: This section should be used to fill in the gaps of factors affecting skid resistance.

Begin the discussion by reviewing materials and pavement factors affecting skid resistance.

It should be emphasized that there are other factors that affect skid resistance besides materials and pavements, and then draw the class into identifying them.

After identifying those factors discuss how they relate to materials and pavement factors.

SESSION GUIDE

SESSION: 33. FACTORS AFFECTING SKID RESISTANCE - SEASONAL, CONTAMINATION, ROAD ROUGHNESS, AND OTHERS

SESSION OBJECTIVES:

As a result of this session, participants will have a complete understanding of those factors which affect skid resistance including seasonal variations, road contamination, road roughness and runoff changes.

REFERENCES: 1, 3, 46, 47, 48, 49, 50

CONTENT:

Factors Affecting Skid Resistance 33-2

Seasonal Variations 33-2

Road Contamination 33-12

Road Roughness 33-13

Runoff Changes 33-14

FACTORS AFFECTING SKID RESISTANCE

There are a multitude of factors that affect skid resistance. In the two previous sessions very important factors affecting skid resistance associated with materials and pavements were covered. However there are factors other than materials and pavement properties that influence skid resistance.

Recap factors affecting skid resistance

Additional factors that affect skid resistance are:

- Seasonal variations
- Road contamination
- Road roughness
- Runoff changes

Discuss additional factors using viewgraph 3301

SEASONAL VARIATIONS

One report begins, "It is well known that the skid resistance of wet roads is lower than that of dry roads. Accordingly, the frequency of accidents involving skidding is higher for wet pavement conditions than dry. Less well known is the fact that wet pavement frictional characteristics can vary significantly from season to season and also intermittently during a given season."(46)

Discuss seasonal variations - ask participants for their experiences.

It has been recognized for some time that pavement surface characteristics undergo seasonal changes which affect the frictional properties. The primary determinants are considered to be exposure to the polishing and wearing actions of traffic and exposure to weather, with the weathering effects - either chemical or physical - tending to offset the traffic effects. For asphalt surfaces, which make up the greater part of the U.S. highway system, minimum levels of skid resistance are generally observed in the late summer and early fall, with maximum levels occurring in the spring.

Discuss seasons of low and high skid resistance and emphasize

Superimposed on these annual changes are short-term variations attributable to the external factors such as amount and timing of rainfall, and possibly to contaminations from oily films, drippings, and other deposits on the surface. In addition to these real changes in pavement surface characteristics, temperature changes affect the properties of the tires involved in the skid resistance measuring system.

Short term variations.

As a result of these factors, the measured skid resistance of a given surface can vary on the order of 10 to 20 or more skid numbers. Thus, it is difficult to state with assurance what the skid resistance of a pavement is, other than at time of measurement, or what the miniumum level of resistance will be. Nevertheless, there are requirements for the systematic identification of the levels of skid resistance on existing highway systems in order to evaluate surfacing materials and practices, and to take corrective measures.

Magnitude of variation in skid resistance

Since it would be difficult, if not impossible, to conduct all inventory surveys of skid resistance at the times when the skid numbers are minimum and most critical, there is a need for procedures to convert measurements to a common seasonal base. Ultimately, it would be desirable to develop factors involving traffic volume and type; temperature, climate, and season; and aggregate sources and surfacing types. These would then be applied regionally to make needed adjustments in measured skid numbers.

Need for procedure to convert measurements to a common seasonal base.

The phenomenon of seasonal variations in skid resistance has been known for many years. At the First International Skid Prevention Conference (1958), Giles and Sabey of the British Transport and Road Research Laboratory noted: "An important discovery that emerged from the skidding investigations carried out in Great Britain in 1931 was the fact that test results for wet surfaces showed a marked `seasonal effect`, giving, for each surface tested, higher valued in winter than in summer." (47)

Seasonal variations have been recognized for several years.

One of the apparent consequences of higher skidding resistance in winter months was the lower incidence of skidding accidents as illustrated in Figure 33-1. Giles and Sabey concluded that "Under British conditions, seasonal changes in coefficients are, on the average, of the order of 0.10 to 0.15, but on some roads differences between midsummer and midwinter as great as 0.3 have been measured."

Higher skid resistance in winter months.

Two determining factors were identified: (1)the direct effect of temperature on changes in the hysteresis loss of rubber tires, and (2)changes in the fine-scale texture of the exposed aggregates brought about by polishing during long, dry periods (summer) and by roughening, probably as a result of weathering during long, wet periods (winter).

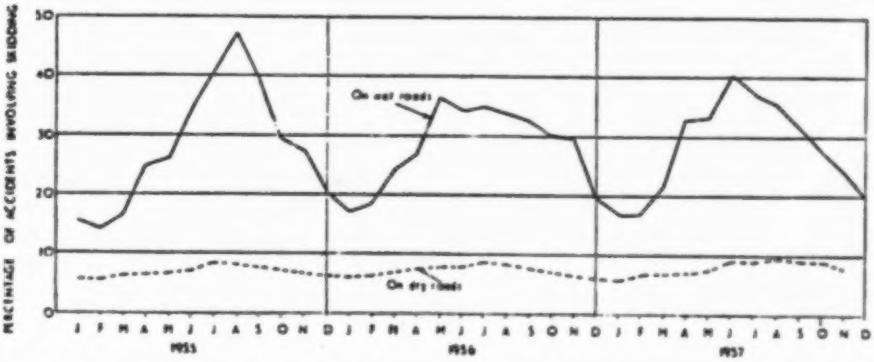
Reasons for seasonal change in skid resistance.

At the same conference, Goetz and Rice referred to these phenomena as "temporal effects" and noted that "tests spaced seasonally, daily, or rain to rain, may show significant differences." They noted that the effect of temperature was a factor, but that this and other factors needed further evaluation.

FIGURE 33-1

TYPICAL SEASONAL VARIATION IN SKIDDING ACCIDENTS FOR A THREE-YEAR PERIOD

Examples of seasonal changes in skid resistance should be discussed along with viewgraph 3302



While a number of State highway departments and other agencies have conducted fairly extensive research on pavement frictional characteristics under wet conditions, little research has been undertaken (until recently) to determine how these characteristics vary from season to season. There has also been little research to identify quantitatively the causes of seasonal variations.

In fact, some agencies are unaware of the phenomenon, and others, while recognizing that frictional properties undergo seasonal changes, doubt the urgency of the problem because of continued problems associated with correlation between accident frequency and measured skid values. This has been compounded due to a general lack of repeatability of measurements and lack of agreement among different skid test units.

The different reactions to seasonal variations should be commented on.

The most comprehensive data bank on seasonal variations has been developed by the Pennsylvania Department of Transportation in the course of evaluating the relationship of different aggregates with the skid resistance of asphalt pavements. A description of this research follows:(48)

Pennsylvania

A detailed study of a series of test strips was made with skid measurements conducted at frequent intervals (1-2 months) over a 4-5 year period. Eleven test sites throughout the state with 77 different aggregate combinations in a standard high-type, dense-graded asphaltic concrete were evaluated, each combination being duplicated for a total of 154 individual test strips.

Discuss the Pennsylvania study and point out how the findings agree with those of other studies.

During the last 3 years of the study, measurements were made at more frequent intervals (minimum of five tests per year) than in earlier years and thus provided greater ranges in skid numbers. For these years, the average seasonal change for the 77 duplicate test strips ranged from 10 SN to 26 SN with an overall average of 14. It is significant that the largest changes were found at the site with the highest average daily traffic volume (ADT), and the smallest changes at the site with the lowest ADT, but this trend was not evident for the intermediate ADT levels.

There is, of course, no assurance that these data encompassed the extreme high or low values for a given year since the timing of the periodic monthly tests was dependent upon weather conditions and equipment availability. These data did not include temperature corrections, because it was found that such corrections made the data more extreme and erratic.

Minimum skid numbers were measured during each of the 10 months (March - December) when tests were conducted although the majority were observed in August and September. The severe winter months (December, January, and February) usually brought about increase in skid numbers, although these were variable. Nevertheless, the overall increases tended to offset the polishing effects in that the plotted curves of skid numbers for the last 3 years showed no consistent upward or downward trends for the annual minimum values.

[redacted]

The Pennsylvania DOT researchers proposed an idealized model, as shown in Figure 33-2, based on the assumptions of a smooth temperature variation, incrementally increasing rainfall occurrence during the winter-spring portion of the year, and no precipitation during the summer-fall season. Figure 33-3 shows an adjustment of the idealized curve to account for the effects of intermittent rainfall. The effects of precipitation on skid numbers are shown in detail for one test strip for a two-month period in Figure 33-4. This figure illustrates that the magnitude of the intermittent changes in skid number can be as large as 15 SN.

Selected Reports Concerning Seasonal Variations

Reports from other States have also included comments on seasonal variations. Some of their quantitative findings are summarized as follows:

Discuss "ideal model" annual cycle pavement SN changes using view-graph 3303.

Arizona's - test with a Mu-meter over 8 miles (12.9km) of portland cement concrete highway gave average readings ranging from 33 in September to 56 in January and then down to 32 in May. An analysis of temperature and rainfall data did not satisfactorily explain the phenomenon.

FIGURE 33-2

"IDEAL MODEL"
ANNUAL CYCLE PAVEMENT SN CHANGE

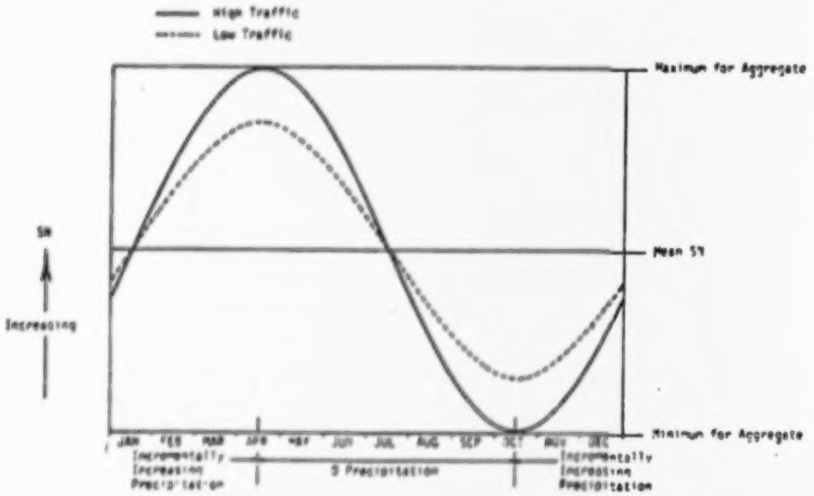


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FIGURE 33-3

ANNUAL CYCLE PAVEMENT SN CHANGE

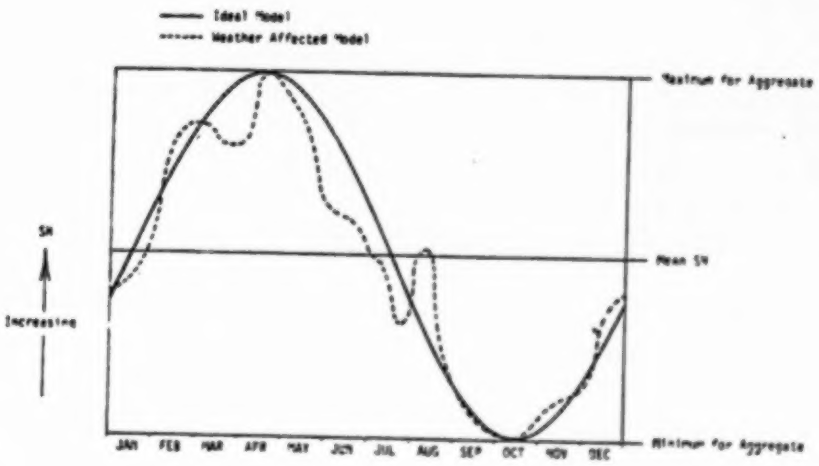
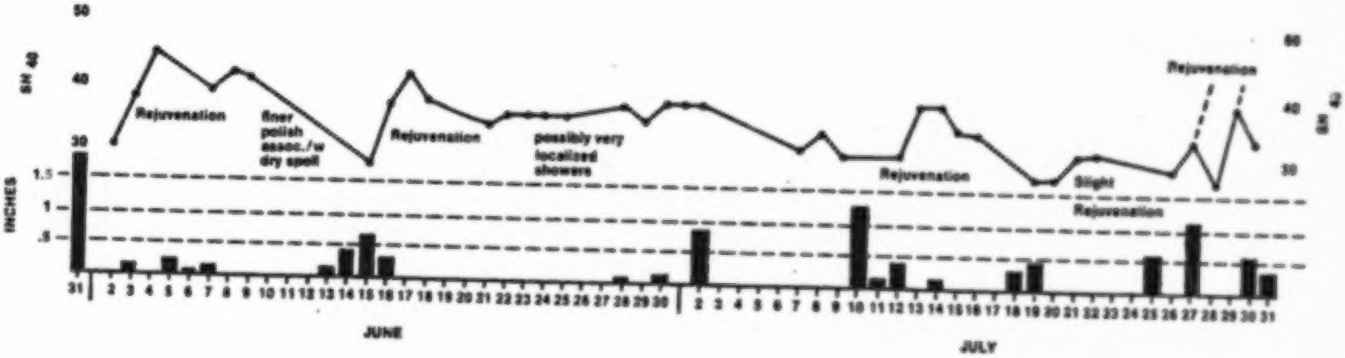


FIGURE 33-4

INFLUENCE OF PRECIPITATION ON SKID RESISTANCE

Discuss influence of precipitation on skid resistance using viewgraph 3304.



1 in = 25.4 mm

Connecticut - has conducted monthly tests on portions of high volume roads over a 4-year period. For asphalt surfaces, seasonal variations as high as 15 SN were observed with low points being reached in July and August as compared to early spring and late fall. The plotted data tend to form sinisoidal curves as proposed by the Pennsylvania DOT, but the primary cause is attributed to development of contaminating films deposited during the high traffic summer months.

High volumes of truck traffic deposit oily contaminations which blacken and soften pavement surfaces. As traffic volume is reduced, weather removes films. For PCC surfaces, high polish and fairly low skid numbers were found in early spring, with the possible causes being the use of sand and snowplows during winter months.

Illinois test results in spring or early summer for an asphalt surface were higher than in fall by 5 to 10 SN. This is attributed to roughening and cleansing of the surface during winter months when abrasives are used for ice control. Contamination by heavy truck traffic leaves less chance for weathering to cleanse the surface.

Kansas has measured seasonal variation as high as 30 skid numbers on one asphalt surface, and in two instances cleansing, cooling rains were followed by increases of 14 skid numbers. Considerable variations were found throughout the year with higher SN values usually in early spring and late fall.

Kentucky, over a 3-year period of monitoring experimental sand-asphalt found variations in the order of 10 SN. Associated with seasonal changes. SN values were lowest during the fall and highest in late winter and spring.

Louisiana has not observed any trends associated with seasons - cold, mild, or hot.

Missouri tested several special PCC and asphalt surfaces at approximately 3-month intervals over a 2 to 3 year period. The maximum annual decreases in skid number from spring to fall were 10 for PCC surface and 17 for asphalt surfaces.

Texas study of four aggregate types in surface treatments showed average seasonal decreases - winter to summer - of approximately 10 skid numbers. The report includes a "polishing theory" based on grit size in relation to rainfall, but does not include weathering or chemical actions.

West Virginia has observed seasonal changes on experimental asphalt test strips over a 3-year period. The averaged data showed reductions from May to October of 14 SN and increases from December to May of 10 SN.

In many areas of the country, winter conditions bring about reductions in traffic density (less polishing) and wetter and more severe weathering conditions (more roughening both on micro and macro levels). Freezing and thawing of wet surfaces can cause disruption and degradation of unsound aggregate particles and scaling of weak or unsound portland cement concrete. Sand applied to improve traction under snow or ice conditions acts as a coarse abrasive to remove polish (increase in microtexture). Studded-tire wear, at a moderate level, may produce a loss of mortar or matrix between coarse aggregate particles (increase in macrotexture). The blades of snowplows can dislodge fine particles and plane down textured surfaces of portland cement concrete. The use of deicing chemicals (chlorides) can cause the scaling of non-air entrained concrete, but air entrained concrete and asphalt surfaces are not affected either physically or chemically.

In consideration of the observations presented previously and depending on the severity of winter conditions, it is concluded that the mechanisms in action during winter months do, in general, effect improvements in pavement surface frictional characteristics.

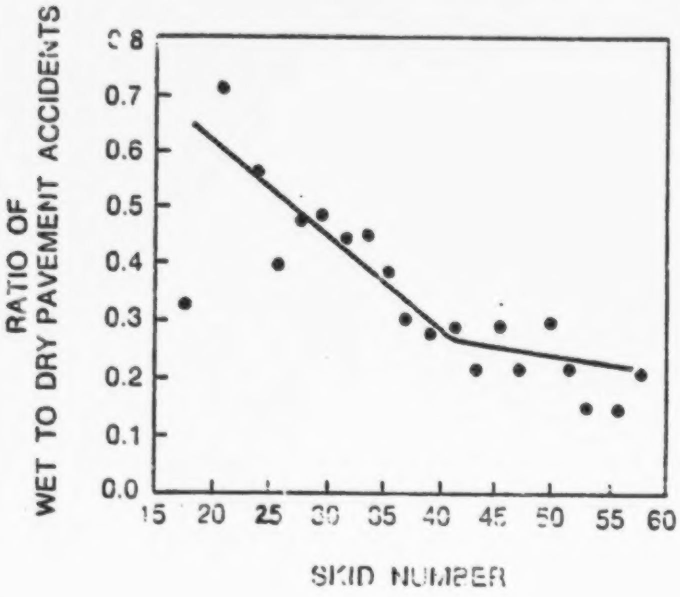
Consequences of Seasonal Changes

If wet pavement frictional characteristics do change with the seasons and intermittently during the seasons, some of the possible consequences should be considered. V-3306

Effect of Seasonal Changes on Wet Weather Accidents - It is generally accepted that the occurrence of wet weather accidents increases with lower levels of skid resistance. Figure 33-5 shows that a decrease of 10 SN from 40 to 30 would increase the proportion of wet pavement accidents from 0.28 to 0.44, or 57 percent. (Note: if wet weather conditions were not contributory to accidents, the value would reflect the proportion of wet pavement time - about 0.12 for these data.)

FIGURE 33-5

RATIO OF WET TO DRY PAVEMENT ACCIDENTS
OF 230 TEST SECTIONS IN KENTUCKY



V-3306

Investigations of Skidding Accidents - A major function of many skid measurement systems is as an after-the-fact investigation of the frictional characteristics at the site of an accident to determine if the skid resistance level might have been a contributing factor. The time of such measurement could be several months after the accident occurs; thus, the single value determined would be relevant only for the period of the test itself, unless there were some means for adjusting this value to conditions at the time of accident.

Identification of Skid-Prone Locations - In implementing the requirements of the Federal Highway Safety Program Standard 12 the Federal

Highway Administration (FHWA) Skid Accident reduction program indicates the need for systematic procedures to identify and correct hazardous skid-prone locations, including the correlation of accident experience with highway data such as measurement of pavement frictional characteristics at particular locations. Such correlations would be confounded if the skid resistance measurements fail to identify hazardous conditions at skid-prone locations due to the occurrence of intermittent or seasonal increases in pavement frictional characteristics.

It should be mentioned that there are those who doubt the reality of seasonal changes and who attribute any observed changes to the lack of precision in measuring skid resistance. Such doubts are understandable; measuring skid resistance can be difficult and frustrating. Dr. Rudolph Hegmon examined whether the lack of precision in measurements could account for variations of 20 or more SN as presented in other reports.(49)

This study verifies the validity of seasonal change and should be discussed in detail

Using skid test data from various sources it was confirmed that the variability in skid testing has a mean standard deviation of 2 SN or better. Using this estimate and assuming that pavement skid resistance, as measured by mean skid numbers, is normally distributed, the following conclusions were drawn:

- Ninety-eight percent of the test results for any given pavement should be within ± 5 SN (± 2.5 standard deviations) of the mean skid number.
- Up to 2 percent of the test data may, by pure chance, fall outside of this 10 SN band.
- Seasonal skid resistance changes of any magnitude cannot be explained by chance alone. If they could, variations would be manifested by increases for approximately 50 percent of the pavements and by decreases over the same period for the remaining pavements.

There is little doubt that systematic, large changes in skid resistance are real and are related to changing conditions. Lack of precision in skid testing may obscure the results by making the changes appear either larger or smaller than they

V 3307
Conclusion concerning seasonal change

really are. For this reason it is important to keep the skid test system current. For monitoring system performance, a continuous record of the system variability is recommended. Increasing standard deviations are clear indicators of problems that need corrective action.

ROAD CONTAMINATION

Road contamination resulting from "traffic film" can, when wet, reduce significantly the skid number of a pavement that has fine asperities only. For example, Kummer (3) reports a rise in wet skid number from 11 to 20 for tests made just before and after a rain preceded by a long dry period. Skid trailer tests were made on wet concrete pavements by the PCA following a 0.6-in. rain that was preceded by 20 days with no measurable precipitation. The data showed that 40-mph skid numbers, obtained after the rain, had increased by a greater percentage on pavements that had the lower values prior to the rain. In general, the skid numbers obtained after the rain increased from 6 to 18 percent, with the 18 percent increase occurring on a pavement with a prior to rain value of 40, while only a 6 percent increase was observed for the pavement with an initial value of 60.(50)

This can be explained by absorption of some water by the pavement and the thereby increased wettability of the surface. Eventually, plain water wets the pavement as well as if a wetting agent had been used. When wettability is low, as when there is a light oil or grease film on the pavement, the water present is more readily displaced by the tire than if there were perfect wetting.

Contaminant films

When contamination is heavy, the skid resistance may be affected adversely. For instance, if oil or another substance with good lubricating properties is present in any significant amount, the tire-pavement interface will be lubricated whether or not there is water, hence friction will be low. However, if the contaminant film is as thin as it usually is in the wheel tracks, and the main contaminant is water, the previously given description of its effects applies. Thick films occur only because of accidental spills, or possibly from the accumulation of oil drippings between the wheel tracks where traffic is rigorously channeled.

Solid contaminants may be a problem. These are most often left after snow and ice have melted. This type of contaminant is dangerous because as a tire rolls onto them the particles act like ball bearings.

Solid contaminants

Paint is another type of contamination that reduces the skid number. Tests obtained by the PCA skid trailer at the Atlanta airport showed that skid numbers in painted areas were reduced from 61 to 29. It is suggested that airport areas requiring painted markings be constructed with colored concrete or with colored aggregates placed in the surface of the concrete.

One other type of contamination - that by deicing agents - is worth mentioning because it occurs frequently. After ice and snow have been melted by them, the pavement dries, usually slowly because of the prevailing low temperatures. The deicing agents further delay the drying process with an attendant effect on the skid resistance, as Figure 33-6 shows. This should not be considered an indictment of deicing agents, but it does serve as a warning to apply them no more generously than necessary for the job to be done. The delay in drying is a function of the amount of deicing agent present.

Deicing agents- explain using viewgraph 3308

The term "viscous hydroplaning" is sometimes applied to the reduction of the available friction by contaminants or by thin water films, particularly when the water contains a large amount of road dust. It really designates only a degree of a phenomenon that exists at all times because there is no known means of removing all water or other contaminating material from the interface between tire and pavement.

ROAD ROUGHNESS

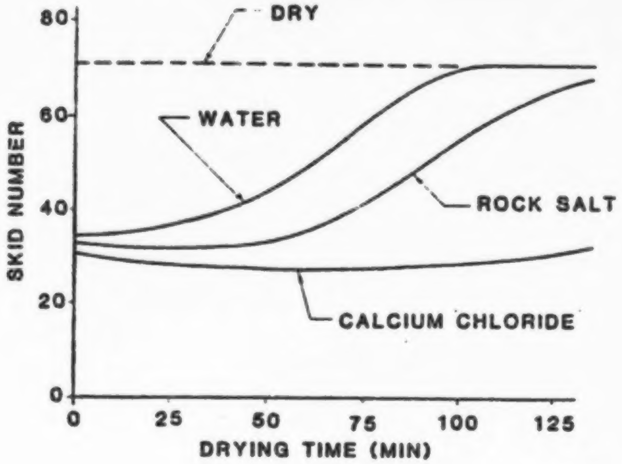
A rough road suface may cause a reduction in the skid resistance that the vehicle can develop, certainly when the pavement roughness is such that wheel hop occurs when the brakes are applied.

General discussion of road roughness and skidding

With modern vehicles on modern highways this is not likely to happen because both, even under the worst of circumstances, are sufficiently well maintained so that wheel hop will rarely be induced. Sometimes an empty trailer of a tractor-semitrailer combination will develop wheel hop during an emergency application of the brakes. This is, however, more the result of the

FIGURE 33-6

DELAY IN THE DRYING OF A WET PAVEMENT
WHEN DEICING AGENTS ARE PRESENT



characteristics of the trailer suspension than of pavement condition.

If pavements are well maintained so that ride is reasonably good, wheel hop or significant reduction of the available skid resistance is not likely to occur. Little hard evidence is available about this, but investigation with skid trailers on rough, though still serviceable, pavements has shown that roughness should not reduce the measured skid resistance. The common criteria for acceptable pavement roughness would therefore seem to be also adequate to prevent reduced skid resistance.(1)

RUNOFF CHANGES

The importance of providing for fast removal of the water that is deposited on a pavement has been stressed. Changes in the pavement cross section usually alter runoff and drying time. Rutting and increasing pavement roughness increase localized water depth and also increase the time required for pavements to dry. In winter, drying speed can be very long or time consuming.

Stress:

- *Importance of fast runoff*
- *Changes in pavement cross section*
- *Increased time required for pavement drying.*

Traffic helps remove water from the wheel tracks by splash and spray, and in heavy traffic this method of water dispersal can be more important than natural runoff, at least during a light rain. But even then, low spots will delay the drying process. In heavy rain and where travel speeds are high, the water depth may become so great that hydroplaning may be induced. Although the vehicle may move out of the puddle rapidly, hydroplaning may continue beyond it because the speed at which a hydroplaning wheel will recover is lower (or the critical water depth is less) than that at which it begins to hydroplane.

- *Traffic removal of water*
- *Low spots*
- *Hydroplanning - beginning and recovery*
- *Water running onto pavement.*

Thus, the effect of the increase in pavement roughness with the life of a pavement may not noticeably change the measured skid resistance (because it is measured with prescribed constant water film thickness), but traffic may still be endangered by the increased tendency of vehicles to hydroplane.

Changes in the water depth on a pavement may also occur because water runs onto the pavement, such as when drainage ditches overflow or when snowbands melt. Some such instances are unavoidable, but the total effect can be minimized through proper design and maintenance.(1)

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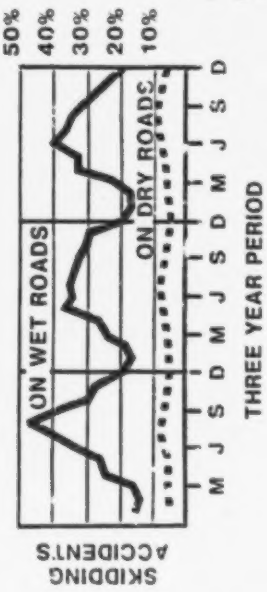
3301

OTHER FACTORS AFFECTING SKID RESISTANCE

- **Seasonal Variations**
- **Road Contamination**
- **Road Roughness**
- **Runoff Change**

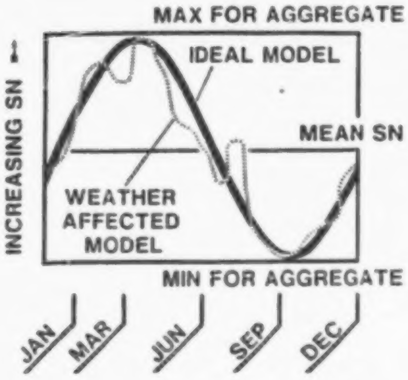
3302

SEASONAL VARIATION IN SKIDDING ACCIDENTS



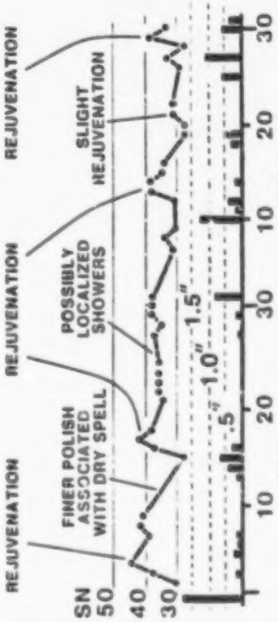
3303

PAVEMENT SKID NUMBER ANNUAL CYCLE



3304

INFLUENCE OF PRECIPITATION ON SKID RESISTANCE



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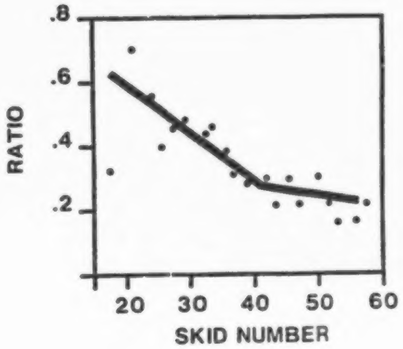
3305

CONSEQUENCES OF SEASONAL CHANGES

- **Accidents**
- **Investigation of Accidents**
- **Identification of Skid Prone Locations**

3306

RATIO OF WET TO DRY PAVEMENT ACCIDENTS



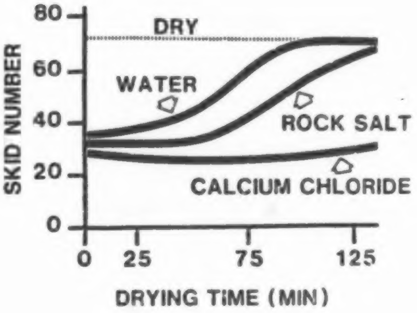
3307

CONCLUSION:

There is little doubt that systematic, large changes in skid resistance are real and are related to changing conditions.

3308

PAVEMENT DRYING TIME WHEN DEICING AGENTS ARE PRESENT



SESSION 41

INSTRUCTION GUIDE

EQUIPMENT - 16 mm Movie Projector, 35 mm Projector, Overhead Projector

AIDS: Viewgraphs 4101-4106

Film: "Open graded Asphalt friction courses"

APPROACH: Overlays are the most used method for restoring skid resistance to pavements.

Attempt to ascertain before the session begins what types of friction overlays are used by participant states.

Develop the theme that advantages other than increases in skid resistance may result from friction overlays.

Make it clear that the purpose of the overlays is to restore skid resistance and not to correct structural problems.

In lecturing about overlays be sure to point out the advantages and disadvantages of each type discussed and emphasize that no one overlay is applicable in all situations.

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SESSION 41

AID: 4101

SLIDES

4101. DOT LOGO

4102. Sprinkle Treatment for Skid Resistance Surfaces

4103. Effective Aggregate Spreading Equipment is Available

4104. Bristowes Spreader

4105. Bristowes Spreader on Transporter

4106. Bristowes Spreader Being Unloaded

4107. Screw in Bristowes Spreader

4108. Screen in Spreader

4109. Part of Spreader Blocked Off Because of Narrow Lane

4110. Sprinkle Aggregate Should Cover 50-75%

4111. Calibrating Sprinkle Rate

4112. Calibrating Sprinkle Rate

4113. Calibrating Sprinkle Rate

4114. Sprinkle Aggregate Should Be Precoated

4115. Stockpile of Sprinkle Mixes

4116. Stockpile of Sprinkle Mixes

4117. Turning Stockpile

4118. Charging Spreader Hopper

4119. Charging Spreader Hopper

4120. Rubber Tired Rollers Are Not Recommended and Should Not Be Used Unless the Mat Has Cooled Sufficiently to Prevent Aggregate Pullout

4121. Rubber Tired Roller Showing Aggregate Pullout

4122. Charging a Front End Roller with Sprinkle Mix Aggregate

4123. Sprinkle Mix on Surface Before Rolling

SLIDES (cont'd.)

4124. Charging Hopper on Spreader

4125. Sprinkle Mix Being Applied

4126. Sprinkle Mix Being Applied - Before Rolling

4127. Rolling Operation

4128. Rolling Operation

4129. Sprinkle Operation

4130. Sprinkle Operation

4131. Rolling Operation

4132. Comparison of Sprinkle and Nonsprinkle Mixes

4133. Sprinkle Mix Operation on Blue Ridge Parkway Near Roanoke, VA

4134. Old Sprinkle Mix

SESSION GUIDE

SESSION: 41. METHODS OF RESTORING SKID RESISTANCE - OVERLAYS

SESSION OBJECTIVES:

Overlays are one of the most used methods of restoring skid resistance to pavements. From this session participants will gain an understanding of the types of friction courses and their applicability to various situations.

REFERENCES: 51, 52, 53, 54, 55

CONTENT:

Introduction 41-2

Open Graded Asphalt Friction Courses 41-2

Dense Graded Asphaltic Concrete Friction Courses 41-7

Factors to Consider in the Decision Process of Whether to Use Open Graded Asphalt Friction Courses 41-8

Asphaltic Concrete With Rolled in, Precoated, Polish-Resistant Chips (Sprinkle Treatment) 41-10

Other Overlays Having High, Durable, Skid Resistant Potential 41-13

INTRODUCTION

Of all the methods used to restore acceptable levels of skid resistance to pavements, probably the most used is that of overlay application for a number of reasons:

- No specialized equipment is necesary;

V 4101

- The technology is fairly well advanced;
- Costs are not prohibitive;
- It is easy to apply;
- Further overlays give structural strength or rejuvenation to the old pavement.

Overlaying is not necessarily the best answer to all situations, and the decision to overlay should be carefully tailored to the situation.

OPEN GRADED ASPHALT FRICTION COURSES

General discussion of open graded asphalt friction courses.

Open Graded Asphalt Friction Courses (OGAFC) have been found to provide flexible pavement surfaces with a number of desirable characteristics. The most important characteristic is the virtual elimination of hydroplaning under usual conditions of rainfall at normal operating speeds.

Forty-nine states plus the District of Columbia and Puerto Rico have constructed open graded asphalt surfaces.

The FHWA design procedure for OGAFC is reproduced from NCHRP Synthesis 49 at the end of this session as Exhibit 4101.(51)

The Advantages and Limitations of Open Graded Asphalt Friction Courses

V 4102

- The potential for hydroplaning during rainstorms is minimized. This is one of the major advantages of the open graded asphalt friction course. The open graded aggregate of the friction course provides drainage channels so that water flows from the surface below the highest asperities of the aggregates. Consequently, good tire-pavement contact is maintained in the presence of large volumes of water.

- Skid resistance at high speeds during wet weather is improved. Because of the macrotexture of open graded asphalt friction courses, the friction numbers of such surfaces do not decrease as rapidly with increasing speed as do the friction numbers of dense graded surfaces. Although an open graded asphalt friction course and a dense graded surface may have equal friction numbers measured at 40 mph (65 km/hr), the measured friction number of open graded friction courses at 60 or 70 mph (95 to 110 km/hr) would be significantly higher than that of a dense graded surface. V 4102

- Splash and spray during wet weather is minimized. With open graded asphalt friction courses much of the water generally flows below the highest points of the surface; thus between the tire and the pavement, there is initially less water present that must be removed, or splashed, to retain tire-pavement contact. In addition, the water can be forced downward into the channels of open graded asphalt friction courses without necessarily being removed laterally, as is the case with dense graded surfaces.

- Road smoothness is improved (due to correction of minor surface irregularities). The improved road smoothness is in comparison with chip seals. Care must be exercised to make sure that the open graded mixture is not used to correct severe rutting or depressions in the underlying pavement. Such action could create a basin for the accumulation of water, which would eventually seep into the base and accelerate structural damage to the pavement.

- Wheel path rutting is minimized. Open graded friction courses depend on the aggregate interlock for its stability and is generally placed at a thickness of approximately 3/4-inch (20 mm). Consequently, rutting is minimized because there is no permanent deformation in the surface layer. However, movement within the underlying pavement or base would result in rutting of pavements overlaid with either open graded asphalt friction courses or dense graded surfaces; although a small amount of rutting in open graded asphalt friction courses will not result in ponding of water in the wheel paths.

- There is less glare at night during wet weather which is a significant advantage of open graded asphalt friction courses. Because most of the water does not pond V 4102 on the surface, the mirror effect of the water film that occurs on the surface of dense graded pavements does not occur on open graded asphalt friction courses. Light reflected from oncoming vehicles and objects adjacent to the highway are dispersed by the open textured surface. The driver's increased ability to discern signs and lane markers under adverse weather conditions is a decided safety benefit of open graded friction courses.

- Riding surfaces are quieter because of less noise from tires. Despite early concerns that open graded asphalt friction courses might be noisier than a dense graded surface, research has shown an open graded asphalt friction course is generally as quiet or quieter than most conventional pavements.

- There are initial cost savings because lesser amounts of high quality skid resistant aggregate are used. Inasmuch as open graded asphalt friction courses are generally laid at thicknesses of 5/8 to 3/4-inch (16 to 20 mm) and dense graded mixtures at thicknesses of 1 to 1.5 inches (25 to 40 mm), the difference in amount of aggregate used is obvious.

- Traffic is permissible on the surface almost immediately after placement. The relatively thin section of the overlay and the openness of the surface permits rapid cooling. In addition, because stability results largely from point-to-point contact of the coarse aggregate, less reliance is placed on the cooling and setting of the asphalt than is the case with either dense graded overlays or chip seals.

- Wet-night visibility of traffic stripes is better because glare is removed. There is an additional benefit: because the paint stripes are not covered with water, the light from a vehicle's headlights is reflected from the paint stripe back to the driver. Also, because of the texture of surfaces, paint covers portions of the coarse aggregate not subject to continuous wear from tires. After the paint stripe has become worn, this residual is particularly effective in providing night visibility, even though the daytime effectiveness may be well below that desired.

- Ice formation on the surface may be retarded. Universal agreement does not exist on this point. Whether ice formation occurs sooner or later on open graded asphalt friction course as compared with dense graded mixtures depends greatly on the atmospheric conditions and temperatures existing during the storm. However, even when snow is trapped in the open graded texture slipperiness is often not as great as would appear, inasmuch as traction is maintained by the high points of the aggregates.

- Driver stress and fatigue is reduced during wet weather. During rainstorms, the combination of a drier surface, reduced splash and spray, and less glare at night gives the driver a feeling of confidence. Fewer distractions permit the driver to give more attention to the normal traffic conditions.

These advantages are generally supported by the performance of a number of installations throughout the country. However, certain limitations of and restraints on open graded asphalt friction courses also must be considered before a decision is made to use this type of mixture at any specific site.

Requirements for Open Graded Asphalt Friction Courses

One basic requirement for open graded asphalt friction courses is the availability of a high quality nonpolishing aggregate. A high friction

General discussion about problems with open graded asphalt friction courses.

number cannot be maintained with aggregates that do not have adequate microtexture and resistance to polishing and degradation under traffic. If such aggregates are unavailable, combinations of several available materials in dense graded surfaces might provide better skid resistant surfaces over the long run.

An open graded asphalt friction course should not be used directly over structurally inadequate pavements. Little, if any, structural strength is added with the open graded asphalt friction course, and a pavement in structural distress must be upgraded or rehabilitated prior to its application. An open graded asphalt friction course may be applied as the final surface to such reconstructed pavements.

Temperatures for placing Open Graded Asphalt Friction Course are more critical than they are for placing dense graded overlays. Placement at temperatures below 60 degrees F (16 degrees C), can lead to poor adhesion and subsequent bond failure. Placement at ambient temperatures above 100 degrees F (38 degrees C), may lead to nonuniformity and flushed areas in the finished pavement because of excess asphalt flow in the haul trucks or pavers.

Costs per ton of mixture are generally higher for open graded mixtures than they are for dense graded mixtures. However, the greater coverage in square yards per ton of open graded asphalt friction course because of higher void content and thinner course thickness offsets this factor to a great extent.

Problems Associated With Open Graded Asphalt Friction Courses

A report by the AASHTO Subcommittee on Maintenance identified the following maintenance problems associated with open graded asphalt friction courses:(52)

V 4103

- The use of chemicals for snow and ice control is increased.
- Reflective cracking is as likely to occur as with any other thin bituminous course.
- Petroleum product spills cause rapid deterioration of the materials.

- Handwork in placement creates a different surface texture.
- The expected service life may be shorter than that of dense graded pavements.
- Patching is difficult.
- Early preventive maintenance is necessary.
- The pavement remains wet longer.
- Provision must be made in the shoulder area to allow free flow of water collected in the open graded asphalt friction course.

These disadvantages were listed as reported by individual states, but they do not in all cases represent a consensus. There are differences of opinion concerning some of them, and more recent evidence indicates that earlier opinions may have been in error.

DENSE GRADED ASPHALTIC CONCRETE FRICTION COURSES

The most common overlay used in the United States is the dense graded hot plant mixed asphaltic concrete.

Emphasize dense graded asphalt friction courses - use the approach that it is the most familiar one to highway men

Overlays can be applied for reasons other than improvement of skid resistance. They may be necessary to improve a worn, pitted or rutted surface, to restore structural capacity, or to act as a new riding course on a concrete pavement. In any case, whether used for other reasons or whether used solely as a method of improving skid resistance, this method of restoring skid resistance requires careful selection of aggregate. The aggregate chosen should have good skid resistance initially and be resistant to wear and polish so that its anti-skid properties are not prematurely lost.

The following advantages can be given for a dense graded asphaltic concrete compared to open graded mixes:

In discussing the advantages of dense graded asphalt friction courses use viewgraph 4104

- Conventional mix with greater experience available at all stages of design, mixing plant and application.

- Greater tolerances in mix proportions, mixing temperature, haul methods and laying procedure can be accepted compared to open graded mixes.

- Can use lesser quality aggregates if highest quality non-polishing aggregates are economically unavailable, and still maintain an adequate skid resistance over the long run.

- Since dense graded overlays are generally laid in 2 to 1 1/2 inch (50 to 40 mm) thicknesses, there is a bonus effect of being able to even out rough, pitted or rutted surfaces, and provide increased pavement strength. *V 4104*

- Provides smooth riding surface over rutted or irregular pavements.

- Probably more economical then open graded overlays, particularly in the long run when service life is considered.

- Less problems with use of chemical and salt for snow and ice control, and with deterioration due to spillage of petroleum products.

FACTORS TO CONSIDER IN THE DECISION PROCESS OF WHETHER TO USE OPEN GRADED ASPHALT FRICTION COURSES

With the present state of knowledge, no criteria can be applied universally when a decision must be made about whether or not to use an open graded asphalt friction course. The evidence is very strong that the use of some type of open graded surface providing good lateral water drainage offers the best available type of construction for minimizing the problems of hydroplaning and splash and spray from other vehicles. For highways with low speeds or in situations with adequate drainage other types of surfaces may provide equal service more economically. The decision for each project must be made on the basis of expected traffic demand (volume and speed), availability of materials, overall cost, and effects on maintenance of traffic during snow and icing conditions.

Several states have adopted criteria based on expected amount of traffic and speed permitted. In Georgia, for example, Open Graded Asphalt Friction

Course is used in construction of all new Interstate highways that have asphalt pavements and all Interstate resurfacing with asphalt pavements. In addition, Open Graded Asphalt Friction Course are used in other projects, according to the following guidelines.

"Recommended for multilane roadways with uncontrolled or limited access and posted speed limits of 40 mph (65 km/hr) or greater where rapid lane change movements and sudden deceleration or acceleration of the vehicle is to occur."

"Recommended for two-lane roadways where the traffic level is moderate to high and frequent passing movements or sudden stops are likely to occur. Posted speed limits should be 40 mph (65 km/hr) or greater and shoulders or right of way provide for limited or inadequate space for refuge or recovery. Particular consideration should be given to roadways with sudden changes in alignment or grade."

"Consideration is also recommended for localized problem areas where increased traction under wet conditions is desired. Open Graded Asphalt Friction Course should also be considered for corrections of intersections or other localized areas where accident experiences indicate a need."

In Louisiana, the adopted policy requires the use of asphaltic concrete friction course (that state's term for Open Graded Asphalt Friction Course) on highways that carry daily traffic volumes from 2,000 to 2,999 per lane and that have speed limits greater than 45 mph (72 km/hr). In this situation, either slag, stone, or expanded clay may be used for the aggregate. Open Graded Asphalt Friction Course must also be used for highways with traffic volumes in excess of 3,000 vehicles per lane and with speed limits greater than 45 mph (72 km/hr). In this situation, only slag or stone may be used as the aggregate. Also, the underlying pavement in this situation must be dense graded asphaltic concrete.

FHWA Technical Advisory T5040.13 "Open Graded Asphalt Friction Courses" dated January 11, 1980 contained an overview of information on this subject including recommendations on the appropriate use of Open Graded Asphalt Friction Courses.

Film: "Open-graded asphalt friction courses"

ASPHALTIC CONCRETE WITH ROLLED IN, PRECOATED, POLISH RESISTANT CHIPS (SPRINKLE TREATMENT)

In large areas of the United States the predominant rock available for road aggregate is limestone. Most rocks that are calcareous in nature, and limestone in particular, are very polish susceptible. In these areas polish resistant aggregates have to be shipped in at considerable cost. To cut down on the shipping and handling of the polish resistant aggregates, sprinkle treatments were developed.

Clarify why sprinkle treatments are used. Make it clear that sprinkle treatments ar still experimental.

With the sprinkle system a technique is employed in which highly skid-resistant aggregates are precoated with an asphalt material and then sprinkled immediately behind the paver and rolled into the surface. One design called for 100 percent limestone in the hot plant mix and some 3 to 5 lbs/sq yd (1.6 to 2.7 kg/sq m) of skid resistant aggregate to be sprinkled on top of it. Other designs specify anywhere from 3 to 10 lbs/sq yd (1.6 to 5.4 kg/sq m) depending upon the density of the aggregate used. The skid resistant aggregate may be either natural or lightweight. Since srinkle treatments are in an early stage of development, the durability of this treatment is still unknown.

Construction Procedure for a Sprinkle Treatment

The following narrative of the sprinkle construction procedure is one that was used in a Florida demonstration project.(53)

The sprinkle aggregate (granite) was precoated with 0.75 percent of standard asphalt cement viscosity grade AC-20 one day prior to the beginning of placement of the surface course. The sprinkle mix was stored in an aggregate bin in a layer approximately three feet high, and water was sprayed on the material until it cooled in order to keep the individual particles from sticking together.

The average measured temperature of the sprinkle mix at the time of production was 289 degrees F (143 degrees C).

The placement of the surface course and sprinkle treatment was begun on December 12, 1978. Immediately following the paving machine and before compaction, approximately 5 lbs/sq yd (2.7 kg/sq m) of pre-coated granite chips were spread with a

Bristowes Mk V Hydrostatic pre-coated chip spreader. The spreader is designed such that it spans the entire 12 feet (3.7 m) of paving and is supported by tandem wheels located outside the edges of the freshly placed concrete mat. The Bristowes spreader is equipped with a powered self-trimming traversing hopper which automatically loads the storage bin when the control lever is operated. The traversing hopper was charged with pre-coated chips with a front-end loader operating on the shoulder of the roadway. There were no problems encountered as fluted rotors at the bottom of the storage bin fed a uniform application of chips onto the surface of the hot mat.

The chip spreader followed the paving machine throughout the job at a speed of approximately 22 to 25 feet per minute (7.2 to 8.2 m per minute).

Compaction of the mat was begun immediately behind the chip spreader. The following rolling pattern was established:

Rolling pattern use

V 4105

- Ten Ton Steel-Wheel Vibratory Roller
    1. Three coverages with vibration on lead wheel.
    2. Four coverages without vibration.
- Six Ton Traffic Roller
    1. Five coverages.

The temperature of the mix at different intervals during the construction phase were measured at several locations throughout the job.

There were no problems encountered in seating the pre-coated aggregates into the freshly placed paving mixture.

Economic Benefits of Using Sprinkle Treatments

The cost savings using sprinkle treatments are dependent on the nearness of the project to non-polishing aggregate.

Since it is not possible to state exact savings in all cases two following examples are cited:

Florida (52)- The cost of the sprinkle treatment including asphalt cement was 0.12 per sq/yd (0.14 per sq m).

Comparing the sprinkle treatment process to the fine dense graded mixtures which are designed specifically to improve the average friction of Florida roads the comparison shows that the costs are:

- Friction course average $1.62 per sq yd ($1.94 per sq m).
- Sprinkle treatment plus leveling course $1.52 sq yd ($1.82 per sq m).

Iowa (54) - Requirements of a project in southwest Iowa, where non-polishing aggregate does not exist, requiring either 35 percent of the aggregate in a 1 1/2 inch (40 mm) surface course be non-polishing or the surface be sprinkle treated as presented as an illustration of the possible savings.

One lane mile of 1-1/2 inch (40 mm) surface course requires 1042 tons of aggregate. If the surface course used 100 percent local limestone at 4.95 per ton and 53 tons of quartzite sprinkle treatment costing 5.50 per ton plus .10 per ton mile for 190 miles, plus 40.00 per ton to coat and spread, the cost would be 8,576. per mile. Costs for the same mile using 677 tons of limestone and 365 tons of quartizite in the surface course would be 3,351 for limestone and 8,942.50 for quartzite for a total of 12,293 per mile. The savings realized by using the sprinkle treatment would be 3,717. Significant savings in haul costs alone could be realized since the haul exceeds 70 miles, which would not be uncommon in many areas.

In addition to the savings realized in the total aggregate expenditures, natural resources, including the high quality aggregate and gasoline for transporting would be conserved.

A rule of thumb to approximate skid numbers when using a sprinkle mix is that the skid resistance will be equivalent to a friction course constructed with the same aggregate.

OTHER OVERLAYS HAVING HIGH, DURABLE, SKID RESISTANT POTENTIAL (55)

- Gap graded asphaltic concrete - a hot plant mixture of asphalt cement with a gap graded aggregate, in which special consideration to wear and skid resistance is given in selection of the coarse aggregate and the aggregate gradation.

- Epoxy modified asphaltic concrete - a hot plant mixed dense graded aggregate and epoxy-modified asphalt binder, in which special consideration to wear and skid resistance is given in the selection of the aggregate.

- Asphalt seal coat - the application of asphalt binder, followed immediately by an application of aggregate that has been selected with special consideration to wear and skid resistance.

- Rubberized asphalt seal coat - the application of rubberized asphalt binder, followed immediately by an application of aggregate that has been selected with special consideration to wear and skid resistance.

- Epoxy asphalt, calcined bauxite chip seal - the application of an epoxy modified asphalt binder, followed immediately by an application of a specific calcined bauxite aggregate.

Discuss other friction overlays using viewgraph 4106

EXHIBIT 4101

FHWA DESIGN PROCEDURE

Material Requirements

1.1 It is recommended that relatively pure carbonate aggregates or any aggregates known to polish be excluded from the coarse-aggregate fraction (material retained on the No. 8 sieve). In addition, the coarse-aggregate fraction should have at least 75 percent (by weight) of particles with at least two fractured faces and 90 percent with one or more fractured faces. The abrasion loss (AASHTO T 96) should not exceed 40 percent.

1.2 Recommended Gradation for Open-Graded Asphalt Friction Course.

Sieve Size[a]	Percent Passing[b]
1/2 in.	100
3/8 in.	95-100
No. 4	30-50
No. 8	5-15
No. 200	2-5

[a] U. S. Sieve Series.

[b] By volume. (This is the same as by weight unless specific gravities of aggregates being combined are different.)

1.3 The recommended grade of asphalt cement is AC-10, AC-20, or AR-40, AASHTO M 226. For AC-10 and AC-20, the M 226 Table 2 requirements should apply where such asphalt is available. AR-40 requirements are given in Table 3 of M 226.

Preliminary Data

2.1 Test coarse and fine aggregates as received for the project for gradation unless otherwise provided. If mineral filler is submitted as a separate item, it should also be tested for specification compliance. Analyze gradation results to determine if proportions of aggregates and batching operations proposed by the contractor will meet the job-mix formula and the specification limits of step 1.2.

2.2 Determine bulk and apparent specific gravity for the coarse- and fine-aggregate fractions (retained and passing the No. 8 sieve) for each type of material submitted. Additional specific gravity tests are not warranted when the only distinction between aggregates is size of grading. Using the information verified in step 2.1, mathematically compute the bulk and apparent specific gravity for the coarse- and fine-aggregate fractions (retained and passing the No. 8 sieve) for the proposed job-mix gradation.

2.3 Test the asphalt cement to be used for specification compliance (AASHTO M 226), viscosity-temperature data, and specific gravity at 77.0 F.

Asphalt Content

3.1 Determine the surface capacity of the aggregate fraction that is retained on a No. 4 sieve in accordance with the following procedure (25).

Note: For highly absorptive aggregates, use the procedure described in step 3.3.

K_c is determined from the percent of SAE No. 10 oil retained, which represents the total effect of superficial area, the aggregate's absorptive properties, and surface roughness.

3.1.1 Quarter out 105 g representative of the material passing the 3/8-in. sieve and retained on the No. 4 sieve.

3.1.2 Dry sample on hot plate or in 230 ± 9 F oven to constant weight and allow to cool.

3.1.3 Weigh out 100.0 g and place in a metal funnel (top diam 3-1/2 in., height 4-1/2 in., orifice 1/2 in., with a piece of No. 10 sieve soldered to the bottom of the opening).

3.1.4 Completely immerse specimen in SAE No. 10 lubricating oil for 5 min.

3.1.5 Drain for 2 min.

3.1.6 Place funnel containing sample in 140 F oven for 15 min of additional draining.

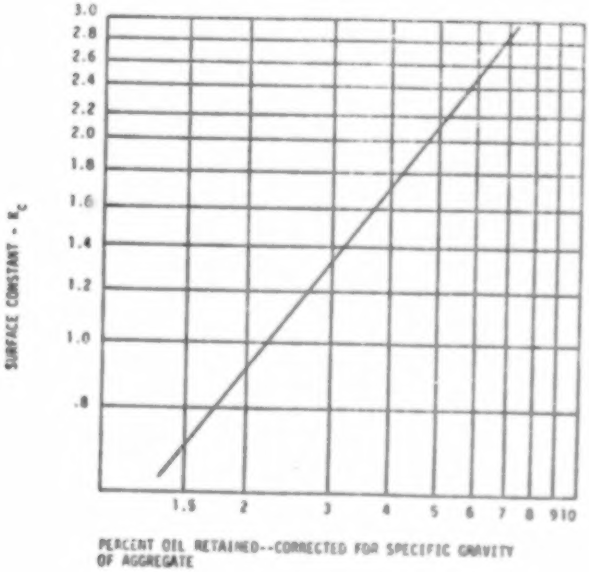
3.1.7 Pour sample from funnel into tared pan; cool, and reweigh sample to nearest 0.1 g. Subtract original weight and record difference as percent oil retained (based on 100 g of dry aggregate).

3.1.8 Use chart shown in Figure A-1 for determination of K_c.

(a) If specific gravity for the fraction is greater than 2.70 or less than 2.60, apply correction to oil retained, using formula at bottom of chart in Figure A-1.

(b) Start at the bottom of chart in Figure A-1 with the corrected percent of oil retained; follow straightedge vertically upward to intersection with the diagonal line; hold point, and follow the straightedge horizontally to the left. The value obtained is the surface constant for the retained fraction and is known as K_c.

3.2 Determine the required asphalt content, which is based on weight of aggregate, from the following relationship (2):



Material used: Aggregate--passing 3/8-in. sieve, retained on No. 4 sieve
Oil--SAE No. 10

$$\text{Oil Retained Corrected (\%)} = \text{Oil Retained (\%)} \times \frac{\text{apparent specific gravity of coarse aggregate}}{2.65}$$

Figure A-1. Chart for determining surface constant (K_c) of coarse aggregate.

$$\text{Percent asphalt} = (2.0\,K_c + 4.0) \times \frac{2.65}{(SG)ca}$$

Where K_c = surface constant

(SG)ca = apparent specific gravity of coarse aggregate (3/8 in. to No. 4)

3.3 For highly absorptive aggregates, use the following procedure for determining K_c and asphalt content.

3.3.1 Follow the recommended design procedure from step 3.1 through step 3.1.3.

3.3.2 Follow the instructions in step 3.1.4, except immerse the specimen for 30 min.

3.3.3 Follow the recommended procedure from step 3.1.5 through step 3.1.7.

3.3.4 Pour the sample onto a clean, dry, absorptive cloth; obtain a saturated surface dry condition; pour sample from cloth into a tared pan; reweigh sample to nearest 0.1 g. Subtract original weight of aggregate and record difference as percent oil absorbed (based on 100 g of aggregate).

3.3.5 Subtract the percent oil absorbed value (see 3.3.4 above) from the percent oil retained value (see 3.3.3 above), and obtain the percent (free) oil retained value. This value represents the percent oil retained value that would have been obtained had the aggregate been a nonabsorptive type. The above technique allows one to evaluate the aggregate's surface and shape characteristics without the overwhelming influence of a large quantity of absorbed oil.

3.3.6 Follow the procedure recommended in steps 3.1.8 and 3.2. The only exception is that the percent (free) oil retained value is used (from step 3.3.5) to obtain K_c. Thus, the asphalt quantity determined is the "effective" asphalt content.

3.3.7 Follow the recommended procedure indicated through sections 4 and 5. Because asphalt absorption is not presently included in the formula for the determination of fine aggregate content, it is particularly desirable that the effects of oil absorption in the K_c test be excluded in the case of the highly absorptive aggregate.

3.3.8 Prepare a trial mixture using an asphalt content equal to or somewhat greater than (try to estimate amount that will be absorbed) the effective asphalt content determined in step 3.3.6 and also using the aggregate gradation as determined in step 3.3.7. Using a suitable technique, such as the test for maximum specific gravity of asphalt mixtures (AASHTO T 209), determine the actual quantity of asphalt absorbed (in percent, based on total weight of aggregate).

3.3.9 Determine the total asphalt content of the subject mixture by adding the effective asphalt content (from step 3.3.6) to the absorbed asphalt content (from step 3.3.8).

3.3.10 Follow the recommended procedure indicated in sections 6 and 7, using the total asphalt content for all subsequent computations and trials (from step 3.3.9).

Void Capacity of Coarse Aggregate

4.1 Use the following procedure to determine the vibrated unit weight and void capacity of the coarse-aggregate fraction (material retained on a No. 8 sieve) of the proposed job-mix gradation (26).

4.1.1 Apparatus

Rammer—A portable electromagnetic vibrating rammer as shown in Figure A-2, having a frequency of 3,600 cycles per min, suitable for use with 115-V ac. The rammer shall have a tamper foot and extension as shown in Figure A-3.

Mold—A solid-wall metal cylinder with a detachable metal base plate and a detachable metal guide-reference bar as shown in Figure A-4.

Wooden Base—A plywood disc 15 in. in diameter, 2 in. thick, with a cushion of rubber hose attached to the bottom. The disc shall be constructed so it can be firmly attached to the base plate of the compaction mold.

Timer—A stopwatch or other timing device graduated in divisions of 1.0 sec and accurate to 1.0 sec and capable of timing the unit for up to 2 min. An electric timing device or electrical circuits to start and stop the vibratory rammer may be used.

Dial Indicator—A dial indicator graduated in

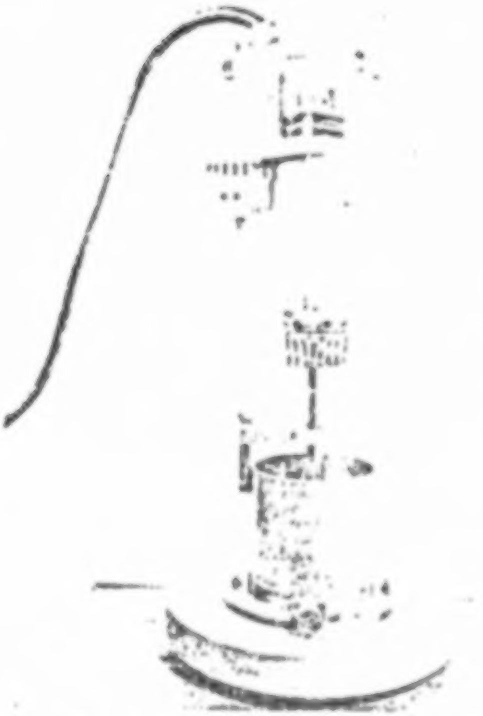


Figure A-2. FHWA vibratory compaction apparatus.

0.001-in. increments and having a travel range of 3.0 in.

4.1.2 Sample: Select a 5-lb sample of the coarse-aggregate fraction from the proposed job-mix formula as verified in step 2.1.

4.1.3 Procedure

(a) Pour the selected sample into the compaction mold and place the tamper foot on the sample.

(b) Place the guide-reference bar over the shaft of the tamper foot and secure the bar to the mold with the thumb screws.

(c) Place the vibratory rammer on the shaft of the tamper foot and vibrate for 15 sec. During the vibration period, the operator must exert just enough pressure on the hammer to maintain contact between the sample and the tamper foot.

(d) Remove the vibratory rammer from the shaft of the tamper foot and brush any fines from the top of the tamper foot. Measure the thickness (t) of the compacted material to the nearest 0.001 in.

> Note: The thickness (t) of the compacted sample is determined by adding the dial reading, minus the thickness of the tamper foot, to the measured distance from the inside bottom of the mold and the end of the dial gauge when it is seated on the guide-reference bar with stem fully extended.

4.1.4 Calculations

Calculate the vibrated unit weight (X) as follows:

$$X = 6912(w)/\pi(d)^2t \text{ (lb/ft}^3\text{)}$$

Where w = wt of coarse-aggregate fraction (lb)

d = diam of compaction mold (in.)

If $w = 5$ lb and $d = 6$ in.:

$$X = 305.58/t \text{ (lb/ft}^3\text{)}$$

where t is in inches

Determine the void capacity (VMA) as follows:

$$VMA = 100(1 - X/U_e) \text{ (in percent)}$$

where U_e = bulk solid unit weight (lb/ft^3) of the coarse-aggregate fraction. U_s is calculated from bulk specific gravity, as determined in step 2.2, multiplied by 62.4 lb/ft^3.

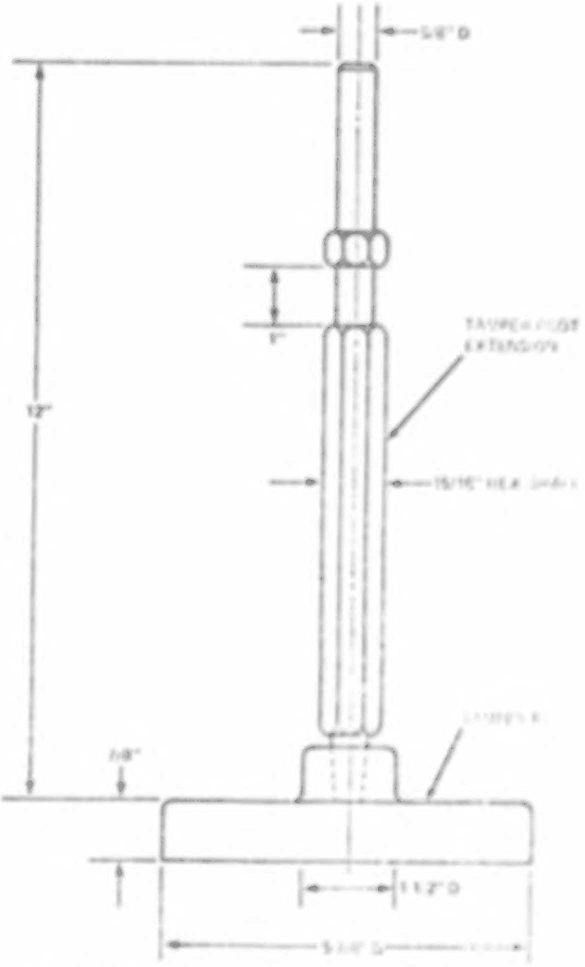


Figure A-3. Tamper foot and extension.

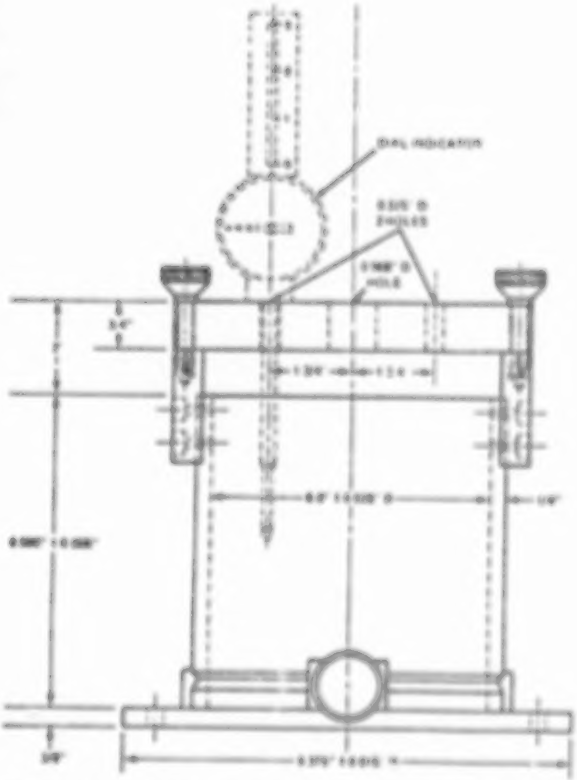


Figure A-4. Cylindrical mold for testing granular materials.

Optimum Content of Fine Aggregate

5.1 Determine the optimum content of fine-aggregate fraction using the following relationship:

$$Y = \frac{[\%\ VMA - V] - [(\%\ AC)(X)/U_a]}{[(\%\ VMA - V)/100] + [(X)/U_f]}$$

Where:

Y = Percent passing the No. 8 sieve (by weight)

X = Actual vibrated unit weight of course aggregate (retained on the No. 8 sieve)

U_f = Theoretical bulk dry solid unit weight of fine aggregate (passing the No. 8 sieve)

U_a = Unit weight of asphalt cement

% AC = Percent asphalt by total weight of aggregate $(2.0\ K_c + 4.0)\frac{2.65}{(SG)ca}$

V = Design percent air voids (15.0 percent)

% VMA = Percent voids mineral aggregate of the course aggregate (retained on the No. 8 sieve), which is $100 - (100X)/U_c$

U_c = Theoretical bulk dry solid unit weight of course aggregate (retained on the No. 8 sieve)

Note: X, U_a, U_c, and U_f are in pounds per cubic foot.

In the above relationship, asphalt absorption by aggregate has been assumed to be negligible. If more asphalt absorption requirements are considered in the test for K_c (see step 3.1), the estimated air voids of 15 percent in the mixture will actually be greater by an amount equivalent to the volume of asphalt absorbed, in percent. This condition provides, if anything, an additional safety factor.

As an alternative to the use of the mathematical relationship, one may use the design chart shown in Figure A-5, provided that the assumptions used in designing the chart are satisfied; that is, the specific gravity values (bulk dry) for the coarse- and fine-aggregate fractions do not deviate beyond the limits of 2.600 to 2.700.

If the value thus obtained for fine-aggregate content is greater than 15 percent, a value of 15.0 percent shall be used.

5.2 Compare the optimum fine-aggregate content (Y) determined in step 5.1 to the amount passing the No. 8 sieve of the contractor's proposed job mix

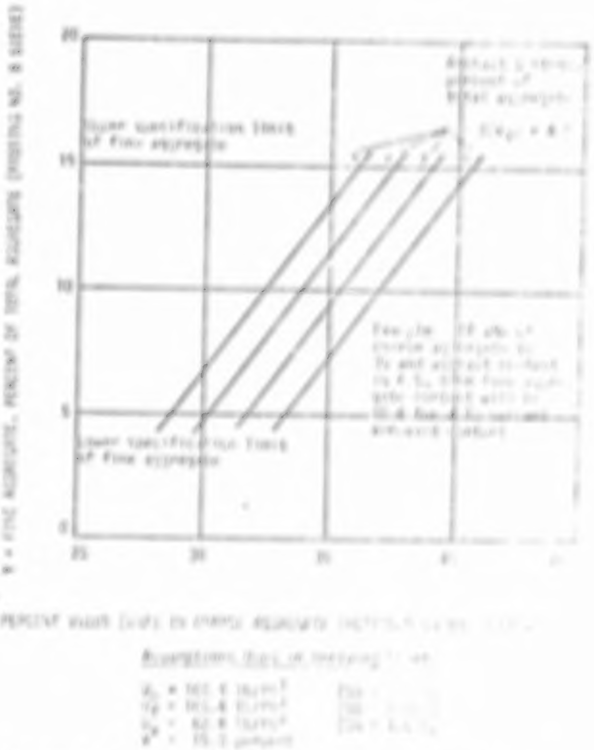


Figure A-5. Determination of optimum fine-aggregate content.

formula. If these values differ by more than plus or minus 1 percentage point, reconstruct a revised or adjusted job-mix formula using the value determined for optimum fine-aggregate content. Recompute the proportions of coarse and fine aggregates (as received) to meet the revised job-mix formula for submission to the contractor.

> Note: If the proposed and revised job-mix gradations are significantly different, it may be necessary to rerun portions of this procedure.

Optimum Mixing Temperature

6.1 Prepare a 1,000-g sample of aggregate in the proportions determined in section 5. Mix this sample at the asphalt content determined in step 3.2 at a temperature corresponding to an asphalt viscosity of 800 centistokes determined in step 2.3. When the mixture is completely coated, transfer it to a pyrex glass plate (diam 8 to 9 in.) and spread the mixture with a minimum of manipulation. Return it to the oven at the mixing temperature. Observe the bottom of the plate after 15 and 60 min (Fig. A-6). A slight puddle at points of contact between aggregate and glass plate is suitable and desirable. Otherwise, repeat the test at lower mixing temperature, or higher if necessary.

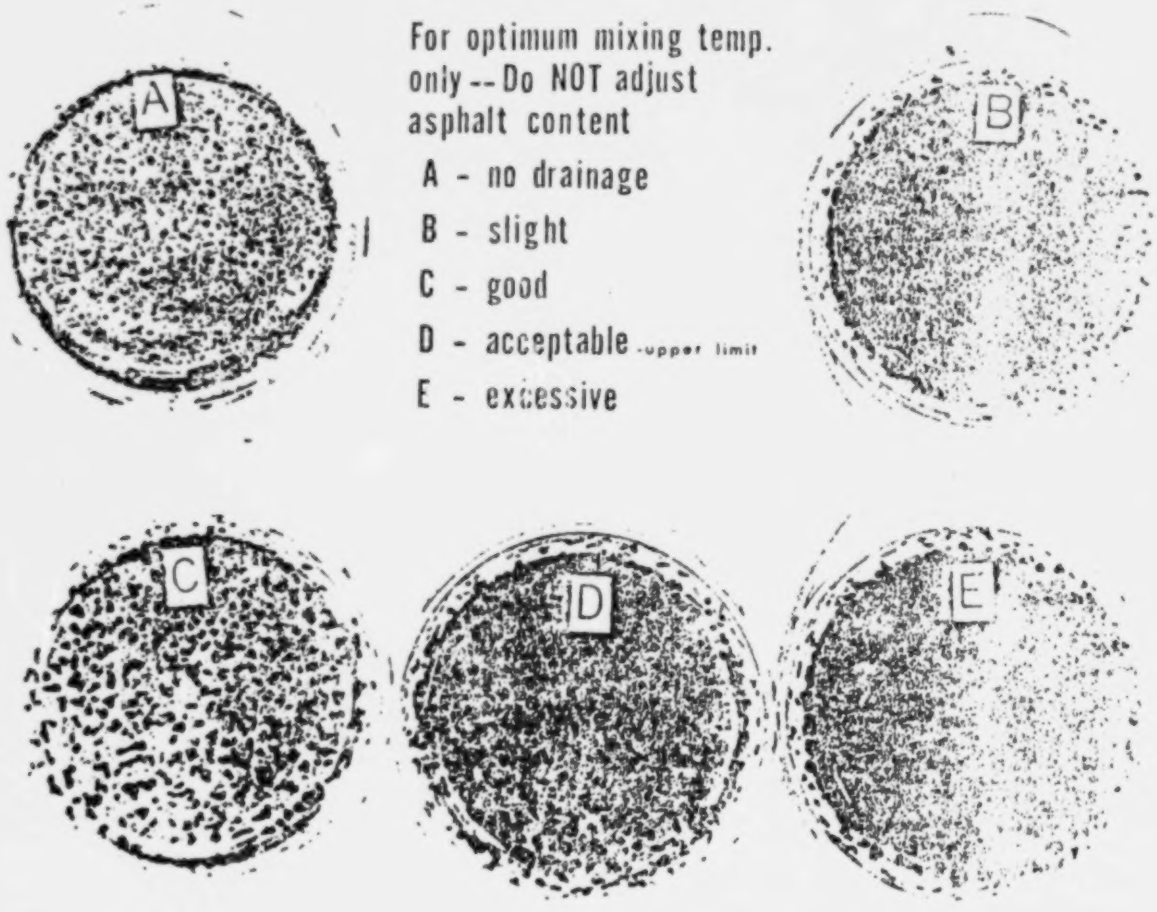
> Note: If asphalt drainage occurs at a mixing temperature that is too low to provide for adequate drying of the aggregate, an asphalt of a higher grade should be used.

Resistance to Effects of Water

7.1 Conduct the Immersion-Compression Test (AASHTO T 165 and T 167) on the designed mixture. Prepare samples at the optimum mixing temperature determined in step 6.1. Use a molding pressure of 1,000 psi rather than the specified value of 3,000 psi.

After a four-day immersion at 120 F, the index of retained strength shall not be less than 50 percent unless otherwise permitted.

> Note: Additives to promote adhesion that will provide adequate retained strength may be used when necessary.



For optimum mixing temp. only -- Do NOT adjust asphalt content

A - no drainage
B - slight
C - good
D - acceptable - upper limit
E - excessive

Figure A-6. Drainage test results.

BEST DOCUMENT AVAILABLE

REPORT ON OPEN-GRADED ASPHALT FRICTION COURSE DESIGN

1. AGGREGATES

A. Proposed Proportions (by weight)

B. Proposed Job-Mix Gradation

Sieve size	Specification limits	Percent passing			
		____	____	____	Job-mix blend
1/2 in.		____	____	____	____
3/8 in.	95-100	____	____	____	____
No. 4	30-50	____	____	____	____
No. 8	5-15	____	____	____	____
No. 16		____	____	____	____
No. 200	2-5	____	____	____	____

C. Specific Gravity--Unit Weight

	Apparent SG	Bulk SG (dry basis)	Bulk solid unit weight (lb/ft^3)
Coarse aggregate (retained on No. 8 sieve)		____	____ (U_c)
Fine aggregate (passing No. 8 sieve)		____	____ (U_f)
3/8 in. - No. 4 Sieve fraction	____		

D. Void Capacity of Coarse Aggregate

Unit weight (vibrated, lb/ft^3) = ____________ (X)

Voids mineral aggregate (%) = ____________ (VMA)

E. K_c Determination

Oil retention (g oil per 100 g aggregate) = ____________

Oil retention (corrected, 2.65 SG) = ____________

K_c (from chart) = ____________

2. ASPHALT

A. Specific Gravity--Unit Weight

Specific gravity at 77 F (25 C) = ____________

Unit weight (lb/ft^3) = ____________ (U_a)

B. Viscosity--Temperature

Asphalt grade = ____________

Temperature (°F)	Viscosity (centistokes)
290	____
275	____
260	____
245	____
230	____
215	____
Target: (-)	(700 - 900)

C. Asphalt Content (AC, %)

Percent asphalt (aggregate basis) =

$$(2.0\,K_c + 4.0) \times \frac{2.65}{\text{apparent SG of coarse aggregate (3/8-in. to No. 4 sieve)}}$$

3. MIXTURE DESIGN

A. Optimum Fine-Aggregate Content (Y)

Using: Formula ________ Chart ________

Where: X = ________ lb/ft^3 VMA = ________ %

U_f = ________ lb/ft^3 AC = ________ %

U_c = ________ lb/ft^3 Y = ________ %

U_a = ________ lb/ft^3

Find: Y = ________ % (specs limit: 5 < Y < 15)

Remarks:

B. Optimum Mixing Temperature

Temperature (°F)	Viscosity (centistokes)	Drainage	Use
____	____	____	____
____	____	____	____
____	____	____	____

C. Maximum Specific Gravity of Mixture (AASHTO T 209)

Specific gravity (vacuum saturation) = ____________

Unit weight (vacuum saturation) = ____________ lb/ft^3

D. Resistance to Effects of Water (AASHTO T 165 and T 167, 200 psi)

Air dry strength (psi) = ____________

Wet strength (psi) = ____________ 4 days at 120 F

Retained strength (%) = ____________ 50% minimum

Air voids (%) = ____________ Bulk volume by dimensional measurement

Remarks:

4. DESIGN SUMMARY

A. Aggregate Proportions (by weight)

B. Job-Mix Gradation

Sieve size	Percent passing Job-mix blend
1/2 in.	____
3/8 in.	____
No. 4	____
No. 8	____
No. 16	____
No. 200	____

C. Asphalt Content

Aggregate basis (%) = ________

Mixture basis (%) = ________

D. Mixing Temperature

Target value (°F) = ________

Range = ________

E. Additives

F. Recommendations Accepted ___ Rejected ___

4101

ADVANTAGES OF OVERLAYS

- Specialized Equipment Not Necessary
- Technology is Well Advanced
- Quick Solution
- Costs are Prohibitive
- Increases Structural Strength

4102

OGAFC ADVANTAGES

- Reduced Hydroplaning
- Improved Skid Resistance
- Reduced Splash/Spray
- Smoother Ride
- Reduced Wheel Path Rutting
- Less Glare
- Quieter
- Cost Savings
- Better Night Visibility of Markings

4103

OGAFC PROBLEMS

- More Chemicals for Snow/Ice
- Earlier Reflection Cracking
- Deterioration from Petrochemicals
- Handwork Creates Surface Difference
- Shorter Service Life
- Earlier P M
- Remains Wet Longer
- Needs Provisions for Drainage

4104

ADVANTAGES OF DENSE GRADED ASPHALT

- Greater Experience at All Stages
- Greater Tolerances in Mix
- May be Used to Even Out Rough, Pitted or Rutted Surfaces and Increase Pavement Strength
- Proven Durability
- Less Problem with De-Iceing Salts and Chemical Spills

BEST DOCUMENT AVAILABLE

4105

ROLLING PATTERN - SPRINKLE TREATMENT

10 TON STEEL-WHEEL VIBRATORY ROLLER

- 3 Coverages with Vibration on Lead Wheel
- 4 Coverages without Vibration

6 TON TRAFFIC ROLLER

- 5 Coverages

4106

SKID RESISTANT OVERLAYS

Asphaltic Concrete
- Dense-Graded
- Gap-Graded
- Epoxy-Modified

Seal Coat
- Asphalt
- Rubberized Asphalt
- Epoxy-Asphalt
- Calcined Bauxite Chip

SESSION 42

INSTRUCTORS GUIDE

EQUIPMENT - Overhead Projector, 35 mm projector

AIDS: viewgraphs 4201-4205

APPROACH: This session will complete the set of currently used methods of restoring skid resistance.

Attempt to ascertain from participants the methods their states use to restore skid resistance other than overlaying.

Most participants from states with portland cement concrete will mention grooving. Although grooving is well known discuss grooving patterns.

Ask participants results obtained from anti-skid treatments.

Attempt to identify unique or innovate techniques that may have wide application.

Identify those anti-skid treatments that are temporary and those that are more permanent in nature.

Discuss costs of anti-skid treatments.

SESSION 42

AID: 4201

SLIDES

4201. Grooves in Old Concrete Pavement

4202. Grooves in Old Concrete Pavement

4203. Diamond Saw Blade Configuration

4204. Bushhammering Machine

4205. Cutting Blades on Bushhammering Machine

4206. Cutting Blades on Bushhammering Machine in Operation

4207. Skid Results of Bushhammered Pavement Compared to Control, .02" Water Depth

4208. Skid Results of Bushhammered Pavement Compared to Control, .04" Water Depth

4209. Bushhammering Conclusions

4210. Apparatus for Applying Acid to Road Surface

4211. Acid Being Applied

SESSION GUIDE

SESSION: 42. METHODS OF RESTORING SKID RESISTANCE - GROOVING AND TEXTURING

SESSION OBJECTIVES:

During this session participants will become familiar with methods of improving skid resistance of pavements including the grooving of portland cement concrete pavements and less conventional methods of treatment such as grinding, bushhammering, acid etching and pavement burning.

REFERENCES: 56, 57, 58, 59, 60, 61, 62, 63, 64.

CONTENT:

Grooving as a Method of Improving Skid Resistance 42-2

Bushhammering 42-4

Acid Etching 42-6

Pavement Burner Treatment 42-7

Pavement Grinding 42-8

GROOVING AS A METHOD OF IMPROVING SKID RESISTANCE

Portland cement concrete pavements textured with drag, have been shown to lose texture in a relatively short time period under heavy traffic volumes.(56) These pavements approach a slippery condition when wet after 20 to 25 million vehicle passes.(57) Many concrete pavements with this type of finish have exceeded that accumulated volume.

Discuss how pavement texture is reduced

The skid resistance on these pavements is due to the sandpaper texture left by the finishing machine. Traffic wears away this finish; the surface becomes smooth. This, when coupled with the inability of portland cement concrete to allow water to penetrate the surface even under pressure, provides an ideal condition for hydroplaning under specified water, tire tread depth, and velocity conditions.

Many methods have been tried to alleviate these dangerous conditions with no single method being completely successful. One method (overlays) was discussed in Session 41.

In the case of portland cement concrete pavement, the surface often becomes slippery with accumulated traffic volumes, but otherwise remains in good condition. The method adopted in this country of increasing the skid resistance of pavements by grooving began in England in the 1950's. The use of grooving as a method of rehabilitating the anti-skid properties of old portland cement concrete pavements was reported as early as 1974 by 19 states.

Grooving is performed by sawing shallow indentations into the pavement with diamond saw blades. In FHWA Technical Advisory T 5140.10 dated September 18, 1979, it was recommended that longitudinal grooving (grooving parallel with the road edge) to the extent practical, be standardized. From the standpoint of compatibility between tire tread designs and pavement texture, the use of 0.095-inch (2.4 mm) wide grooves spaced on 3/4-inch (19 mm) centers with a depth of either 1/8 or 3/16 inches (3 or 5 mm) is recommended by AASHTO. Closer spacings and shallow depth result in less durability while wider spacings add significantly to noise and loss of directional control in light cars. " Groove wander" or swaying of vehicles on grooved pavements has been explained as occurring when the groove pattern matches the tire tread pattern.

Discuss the FHWA recommended groove configuration in conjuction with viewgraph 4201

Comparison of Longitudinal and Transverse Grooving

Almost all grooving of old concrete pavements is longitudinal. Longitudinal grooving assists vehicle control at curves and sites involving lateral movements. However, motorists driving light cars and motorcycles have reported that grooves with 1-inch spacing and 1/4-inch width reduced directional control. Also, with the increased use of smaller, lighter cars and radial tires, complaints of vehicle handling problems on longitudinal, grooved pavements seem to be on the increase.

Discuss the advantages of longitudinal grooving using viewgraph 4202

By following the AASHTO recommended groove spacing and configuration, vehicular handling problems are reduced.

Transverse grooving is the sawing of grooves perpendicular to the road edge and across the entire pavement. Early experiments with this type of grooving created road noise problems for both nearby residents and motorists. The noise problem has been more or less resolved by the introduction of random spacings of the grooves. Another problem associated with transverse grooving is traffic control. It becomes almost essential to close the roadway in order to saw the grooves since the cutting machine must traverse back and forth across the roadway. This also reduces production and increases costs.

Discuss the advantages of transverse grooving using viewgraph 4203

Results of Grooving

Literature reviews make it apparent that longitudinal grooving does reduce wet weather accidents, although the skid resistance as measured in the conventional manner does not increase significantly. The mechanisms that appear to help prevent accidents are: (1) vehicles tend to track in line with the grooves and this reduces skidding, and (2) the grooves provide an escape for water under pressure at the pavement/tire interface, reducing hydroplaning. Why a vehicle tracks in the grooves is not well understood, although one theory holds that the tire surface deforms to the degree that it protrudes down into the grooves.

In one study the indication was that total accidents were reduced by 78 percent. Of this percentage, wet pavement accidents were almost completely eliminated (96 percent) and dry pavement accidents dropped 32 percent.(58) Other studies in Georgia, Indiana, Minnesota and Texas have shown reductions in accidents of 30, 62, 41, and 50 percent, respectively.(59)

Limitations of Grooving

Discuss the limitations of grooving using viewgraph 4204

- In areas where studded tires are extensively used, grooves are quickly destroyed.
- Where the aggregate is soft the grooves quickly spall out.
- Longitudional grooving does not actually increase skid resistance as measured by conventional means and sometimes does create handling problems for small vehicles and motorcycles. However, does significantly reduce accidents.
- Grooves may be destroyed by ice formation.

Specifications for Grooving

Highlights of the California Specifications for grooving of pavements (60) are given here as a guide to the items that require attention when grooving operations are performed. It should be noted that these specifications are chosen as a guide, but are not a universal standard. The specification in its entirety is included as Exhibit 4201.

These specifications govern groove width, spacing and depth for pavements, bridge decks, and the grooves over inductive loop detectors. They also cover the minimum percentage of grooves required that compare to the theoretical number per unit area. Finally, the specifications provide for removal of debris and residue from groove cutting, maximum noise levels during cutting operations, and measurement and payment for grooves cut.

BUSHHAMMERING

Bushhammering is the process of removing the entire surface of a roadway to a desired depth, while leaving exposed fresh, highly fractured aggregate, slightly raised above the surrounding cement. The process works, at least in the United States, much better on portland cement concrete than on bituminous surfaces.

This phenomenon is explained by reviewing how bushhammering machines operate. These machines remove the upper layer by hammering the pavement surface into small particles; but, actually, this is not quite true. The hammers strike the pavement approximately 1500 times a minute but with little force. This sets up a compression-tension reaction, and since concrete is stronger in compression than tension the particles fly off from the surface when the compressive force is removed. The machine removes the surface by the number of impacts rather than by the force of individual impacts. Softer bituminous material tends to clog the cutting heads.

There are several different types of machines but all work on a similar principle. They operate on compressed air, with air requirements that depend upon the number of cutting heads.

In one of the reported experiments the entire surface was removed to a depth of from 1/4 to 1/8 inch (6 to 3 mm) of a portland cement concrete pavement. This consisted of two lanes (one direction) of I-95 near Emporia, Virginia for a distance of 1/4 mile (0.4 km).

The following results were recorded:

- Skid tests showed greatly increased skid numbers after bushhammering for all speeds from 30 to 70 mph (48 to 110 km/hr).
- The increase was greatest for bald tires, and on previously very slick pavements.
- The increase was least for new tires, and on previously good skid resistant pavements.

In comparing longitudinal grooving and bushhammering the following observations were made:

Compare longitudinal grooving and bushhammering using viewgraph 4205

- Both grooving and bushhammering provided space for water to escape from the pavement-tire interface.
- Grooving does not increase the skid resistance as measured in the conventional manner.

- Grooving reduces accidents, but no accident data is available for the bushhammering areas.

- Bushhammering leaves a well defined microtexture, particularly in the large aggregate, and a surface macrotexture that is less conducive to hydroplaning because it facilitates the escape of water at the pavement-tire interface.

- Bushhammering improved the skid resistance.

- Bushhammering costs were about $0.10 per sq ft ($1.08 per sq m.) compared to grooving at $0.20 per sq ft ($2.15 per sq m)(55). Durability data on bushhammering versus grooving is not available.

ACID ETCHING

Acid etching has been experimented with and used to a limited extent for several years on portland cement concrete pavements.(61)

This method of restoring skid resistance is accomplished by acid reacting with the cement and removing it to a point where the fine aggregate (sand) below the surface is exposed.

It should be remembered that concrete pavements experience a reduction in skid resistance when the sandpaper texture is worn off. If, in fact, acid etching can restore this texture, then skid resistance is restored.

There have been in the past a number of highly advertised commercial products on the market, but they have not proven entirely successful.(62)

In 1975 a Virginia study was performed to determine the effectiveness of several acids at different strengths, and to verify reported results from various sources.(63)

It had been reported that skid resistance was being increased by as much as 20 skid numbers with acid treatments. However, it was also reported that the increase in skid number was of a temporary nature and that skid resistance returned to the before treatment level in approximately six months.

The study covered a laboratory phase where four acids at various strengths were considered. From the results of these, two acids at 25 percent strength were chosen for full scale field trials.

Conclusions gained from the study, which are indicative of other studies, were:

- Acid etching significantly increases the skid resistance on portland cement concrete pavements, but the increase is temporary with an effectiveness of approximately six months. For situations where it is not possible to restore skid resistance in a more permanent manner, this method has definite potential.
- A 25 percent application of 100 ml per square foot appeared to be the optimum application.
- A second application of acid is not justified by the increase in skid numbers.
- After a 6 to 10 minute reaction time between the acid and concrete a residue is formed, probably a calcium salt, that greatly retards further reaction.
- Improper use of acid is very dangerous, and adequate protection must be provided for employers and motor vehicles.

PAVEMENT BURNER TREATMENT

Pavement burning has been successfully employed in restoring skid resistance on both concrete and bituminous roadways.

On occasion it happens that a bituminous mixture will have an excess of asphalt or, in some cases, an asphalt grade not suitable for a particular location. When this situation occurs the pavement will flush or bleed in the summer months. An asphalt film over the surface results, and a very slippery situation is produced.

The removal of excess asphalt can be a difficult job. However, one way of removing this material is to burn off the excess. This method has been used by a number of states with good results. In many cases the burner treatment was accomplished by using homemade LP gas fired units.

Experimentation has also been performed with burner treatment of concrete pavements. This causes thin surface spalls the size and depth of which can be regulated by the amount and time of heat application.

PAVEMENT GRINDING

The diamond-grinding process of concrete repair is increasing in usage. This method is performed by diamond-bladed machines that do not tear up the concrete or damage the areas in the vicinity of joints. It was first used to grind off bumps and smooth out pavements. Later the method was used to smooth out old jointed concrete pavements after the pavement slabs were stabilized by pressure grouting and the spall repaired.

When grinding is performed (sometimes as much as an inch [25 mm] is taken off) the surface is left with a corduroy-type texture which gives a high skid resistance.

For this method to be effective in restoring skid resistance, the road must have been constructed with polish resistant aggregates.

Grinding has the advantage over some other methods in that it removes surface irregularities, thereby giving a smoother ride and a highly skid resistant surface.

In Los Angeles County, a contract was awarded which required pavement texturing in 30 different locations to improve skid resistance. A minimum frictional coefficient of 0.35, as determined by surface texture tests (California Test Method 342), was specified. Also specified was the maximum noise level allowable during the texturing operation which was 86 dbA at a distance of 50 feet at right angles to the direction of travel. Apparently, these criteria were met without difficulty.(64)

EXHIBIT 4201

CALIFORNIA GROOVING SPECIFICATION (60)

Description

This work shall consist of grooving the surface of asphalt concrete or portland cement concrete pavement and bridge decks as shown on the plans and as specified in these specifications and the special provisions.

Construction

Grooved areas shall begin and end at lines normal to the pavement center line and shall be centered within the lane width. If new concrete pavement is grooved, the grooving in any lane shall cover the full lane width.

Grooving blades shall be 0.095-inch wide ± 0.005-inch and shall be spaced 3/4 inch on centers. The grooves shall be cut not less than 1/8 inch nor more than 1/4 inch deep. The grooves on bridge decks shall be cut not less than 1/8 inch nor more than 3/16 inch deep. Grooves over inductive loop detectors shall be cut not less than 1/16 inch nor more than 1/8 inch deep.

At the beginning of each work shift, all grooving machines shall be equipped with a full complement of grooving blades that are capable of cutting grooves of the specified width, depth, and spacing.

If during the course of work a single grooving blade on any individual grooving machine becomes incapable of cutting a groove, work will be permitted to continue for the remainder of the work shift, and the Contractor will not be required to otherwise cut the groove omitted because of the failed blade. Should two or more grooving blades on any individual grooving machine become incapable of cutting grooves the Contractor shall either:

- Discontinue work with the affected grooving machine within 50 feet of the location where more than one blade became incapable, in which event the Contractor will not be required to otherwise cut the grooves omitted because of the failed blades; or,

- Continue work with the affected grooving machine for the remainder of the work shift and by other means cut all grooves omitted, including those grooves omitted because a single blade was incapable, by the affected grooving machine within that work shift. The omitted grooves shall be cut before any of the grooving work performed during the time the grooves were omitted will be accepted.

The actual grooved area of any selected two-foot by 100-foot longitudinal area of pavement specified to be grooved shall be not less than 95 percent of the selected area. Grooves which are omitted as permitted for blades which become incapable will be measured as being actually grooved. No area will be measured until omitted grooves, which are required to be cut before the area is accepted, have been cut. Except as provided for omitted grooves due to an incapable blade, any area within the selected area not grooved shall be due only to irregularities in the pavement surface and for no other reason.

Residue from grooving operations shall not be permitted to flow across shoulders or lanes occupied by public traffic or to flow into gutters or other drainage facilities. Solid residue resulting from grooving operations shall be removed from pavement surfaces before such residue is blown by the action of traffic or wind.

The noise level created by the combined grooving operation shall not exceed 86dbA at a distance of 50 feet at right angles to the direction of travel.

Measurement

Pavement grooving on existing pavement will be measured by the square yard. The quantity of pavement grooving to be paid for will be determined by multiplying the width of the grooved area by the horizontal length grooved.

Payment

The contract price paid per square yard for groove existing concrete pavement shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all work involved in grooving the existing concrete pavement, including removing residue, as shown on the plans, as specified in these specifications and the special provisions, and as directed by the Engineer.

4201

RECOMMENDED GROOVE CONFIGURATION

Width -	0.095 Inch (2.4mm)
Spacing -	3/4 Inch (19mm) Centers
Depth -	1/8 Inch (3mm) or 3/16 Inch (5mm)

4202

LONGITUDINAL GROOVING ADVANTAGES

- Reduces Hydroplaning Potential
- Assists Vehicle Control on Curves

Reduces Accidents

4203

TRANSVERSE GROOVING ADVANTAGES

- Good Skid Resistance
- Reduced Splash/Spray
- Reduced Glare
- Better Drainage
- Inexpensive Inclusion in Construction

Reduces Accidents

4204

GROOVING LIMITATIONS

- Studded Tires Destroy Grooves
- Grooves in Soft Aggregate Spall Out
- No Skid Resistance Increase (Longitudinal)

4205

A COMPARISON

	LONGITUDINAL GROOVING	BUSH-HAMMERING
Water Escape	YES	YES
Defined Textures		YES
Skid Resistance	NO	YES
Reduces Accidents	YES	NO DATA

SESSION 51

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraph 5101

APPROACH: This session deals with the various tests in use to evaluate surface properties that affect skid resistance.

Following short descriptions of each test, its uses and drawbacks, a case study is presented on how specifications for skid resistant pavement can be developed.

SESSION GUIDE

SESSION: 51. THE USE OF SKID TEST DATA IN THE DESIGN AND DEVELOPMENT OF SPECIFICATIONS FOR SKID RESISTANT PAVEMENTS

SESSION OBJECTIVES:

The participants will learn how information gained in skid testing can supply valuable input for pavement design and the development of specifications for skid resistant pavement.

REFERENCES: 65, 66

CONTENT:

Introduction 51-2

Tests and Specifications 51-2

Case Study: How Skid Test Data has been Used to Prepare Specifications 51-7

Summary 51-10

INTRODUCTION

In 1966 Congress passed the Highway Safety Act. This was prompted by the increase in accidents and the rising death toll on the nation's highways. As a result, on June 27, 1967, the Secretary of Transportation issued 13 highway safety program standards that were "designed to reduce traffic accidents and deaths, injuries, and property damage resulting therefrom." One of these standards required that every state "have a program of highway design, construction, and maintenance to improve highway safety."

This standard calls for every State to have "Standards of Pavement design and construction with specific provisions for high skid resistance qualities," and "A program for resurfacing or other surface treatment with emphasis on correction of locations or sections with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces."(65)

The stated policy is that pavement surfaces should be constructed and maintained for the best possible skid resistance.

TESTS AND SPECIFICATIONS

One of the most difficult problems for highway engineers is the development of tests and specifications to control microtexture of aggregates and the degree to which the microtexture will be retained during the service life of a pavement.

V 5101

The necessity exists for continuing field evaluation of the wear-polish characteristics of various aggregates and combinations of aggregates having different mineralogical compositions. Although continuing field efforts are important, it is also essential to have laboratory tests and criteria that allow answers for decisions on the suitability of aggregate sources. The importance of such tests should be stressed since the proper choice of an aggregate is not only based on its angularity, microtexture, and susceptibility to polish-wear, but also on availability, cost, and numerous other required properties. The proper design of a pavement is difficult, and specifications and standards which do not provide proper control and guidance may be very costly.

Wear/Polish test

Petrograpic tests

Significant tests in characterizing resistance to wear-polish are the various petrographic tests which describe the aggregate and its mineralogical composition. This analysis may prove very useful in selection of aggregates if such tests or combinations of test results are correlated with field performance. Special cases require special tests. In the case of limestones and dolomites, which sometimes polish very rapidly, the acid insoluble residue test is being explored and has been used in certain specifications (ASTM D3042 is the applicable standard). As with many tests of this type there is controversy about the interpretation and use of the results.

Acid insoluble test

The acid insoluble residue test is recommended for use as a laboratory evaluation test. It should not be considered as a principal means of predicting resistance to change in tire-pavement friction as governed by polishing action of traffic. The test should be considered as a very useful tool when used in conjunction with results of field performance of a given aggregate(s), or when combined with other laboratory tests such as a polishing test and petrographic analysis."

British wheel polishing machine

Perhaps the most significant test for predicting the resistance to change during service life is the wear-polish test. Numerous studies have been performed pertaining to this type of test but a fully acceptable test is not presently available. However, the well-known British wheel polishing machine is being studied by ASTM along with other devices for wear and polish determinations. Texas uses this machine for an accelerated polish test for coarse aggregate (Texas H.D. Test Method 438-A, January 1, 1974).

There are two approaches in attempts to provide design information on aggregate wear and polish resistance, other than experience in field testing. The first approach involves a laboratory system which determines the change in microtexture of selected aggregate particles. The second involves laboratory simulation of field conditions.

The British wheel polishing machine is an example of the first laboratory testing system. Currently, the quantitative measure of microtexture is a very difficult problem, and it is best performed with a low speed friction tester like the British portable tester. This instrument provides friction readings which are indicative of the lower speed range (below 30 mph [48 km/h]) in which the dominant factor is micro|texture of the aggregate particles. Through the use of this system one may obtain information on coarse aggregates for use in asphaltic concrete and aggregate (screening) seal coats such as 1/2-3/8 (12-10 mm) and 1/4 inch (6 mm). However, it is not possible to study fine materials with this method.

The second approach, a laboratory simulation, is the most logical development for characterizing the total effect of traffic on various pavements or surface treatments. The device most often used to simulate field conditions is the circular track (ASTM E660-78 is the applicable standard). Other systems include a stationary spinning wheel wearing and polishing on a fixed area of the specimen, and smaller instruments that employ small rotating rubber devices scrubbing on circular specimens.

One of the most difficult problems with such simulation systems is the forming of a test specimen that is representative of the pavement surface. For example, the preparation of portland cement concrete test surfaces must provide the same finish and strength as found in the field, and with the cement, water, and aggregates in the same proportion as found in field conditions. This may or may not be possible during preliminary design.

The use of additional water, for example, during construction may result in a weakened mortar. A strong mortar is desirable since a weak mortar will wear at a rapid rate and lose aggregates which provide the microtexture. In this case, rapid wear is the dominant factor in the future field condition, but may not show in laboratory studies.

It appears possible to produce realistic test specimens for the various forms of asphalt surfaces although sufficient results are not available to provide conclusive recommendations.

Laboratory circular track machines

A problem with a circular track-type machine is the possible displacement of the surface because of the scrubbing motion of the wheel rotating on a short radius. A further problem is the difficulty of tracking in the same area. Most units presently under study, therefore, have a variable radius feature.

A wear and polish machine must produce accelerated results; therefore, most test methods employ some additional form of abrasive. The need for standarization of abrasives is great.

Macro-texture tests

As has been mentioned previously, both microtexture and macrotexture are involved in providing proper skid resistance over the range of speeds encountered in pavement and runway operations. Although microtexture comes into play at all speeds, macrotexture is essential at speeds above 30 mph (48 km/hr). Therefore, it seems necessary that the full friction curve over a range of speeds be obtained from the wear-polish efforts with the circular or linear track.

BPT for indirect measurement of microtextures

Schonfeld method. Sand patch tests. Outflow meter.

The British portable Tester will provide readings that indicate the change in microtexture and represent the friction curve up to about 30 mph (48 km/hr). Beyond this point macrotexture is of importance. The measurement of changes in macrotexture may be accomplished by use of either the Schonfeld method (ASTM E559 is the applicable standard), the sand patch test or the outflow meter. However, these measurements must be correlated with friction readings from field studies.

Another system is actual field studies of trafficked surfaces. Skid resistance measurements are taken at frequent intervals with standardized ASTM equipment. There is a need for frequent measurements since there can be significant variations caused by relatively minor changes in environmental conditions. The Pennsylvania DOT studies indicate that this system will provide information of value within one to three years under heavy traffic. There are growing indications that practical equilibrium conditions are reached during this period.

If we are to obtain useful data, it is essential that additional field sections be paired with duplicate test surfaces in the laboratory. This effort will improve future efforts to standardize a method of determining the effects of aggregate wear and polish on tire-pavement friction values over the entire range of speed.

Quoting from the United States Government Department of Transportation FHPM 6-2-4-3:

> "In order to fully understand and evaluate current pavement design and to establish a logical program for the correction of skid prone locations, it is essential that each state have a program

> of making skid resistance measurements. Sufficient measurement data should be available to enable the designer to accurately predict the skid resistance performance of a given pavement mix design utilizing a particular aggregate or aggregates, and constructed according to accepted procedures. (66)

Only gradations, mixes, and construction methods specifically directed toward skid resistance properties should be used for pavement surfaces. Therefore, current pavement specifications, available materials, mix designs, and construction methods should be examined to determine if the resulting pavement surfaces provide and maintain proper skid resistance properties.

This examination should include the determination of the frictional, polishing, and durability characteristics of surface course aggregates, mixes, and surface finishes. Such tests as the insoluble residue test and the accelerated polishing test are available to determine polishing characteristics of aggregates in the laboratory. Test methods such as the outflow meter, sand patch test, stereo photographic interpretation and measurements such as skid numbers and speed gradients are available to evaluate the skid resistance of completed pavements.

Sufficient data should be developed by laboratory testing correlated with field tests, or by field tests alone, to enable the designer to adequately estimate skid resistance properties, including the loss of skid resistance from traffic and the change in speed gradient throughout the design life of the surfacing. The prediction of skid resistance loss due to polishing under traffic, and loss of surface voids and texture depth will require performance data collected over a significant time period. However, reasonable estimates, sufficient for an evaluation of presently used surfaces, can be obtained by measuring properties of recently constructed surfaces and surfaces of similar design which have been exposed to large numbers of vehicle passes. The loss in skid number and the increase in speed gradient for the estimated volume of traffic obtained in this way can be assumed to be representative of the range in values to be expected for the combination of aggregate, mix design, and construction method tested.

The amount of wet weather skidding is a function of traffic volume and the amount of time the pavement surface is wet, as well as the speed of traffic and pavement skid resistance. The retention of high skid numbers and low speed gradients throughout the life of the pavement becomes essential for conditions of high traffic volume and high percentages of wet pavement time.

CASE STUDY: HOW SKID TEST DATA HAS BEEN USED TO PREPARE SPECIFICATIONS

During 10 years of research in the State of New York, thousands of skid tests have been performed on pavements containing aggregates from nearly every crushed-stone source that supplies asphalt concrete producers in the state.(65) In addition, over 10,000 asphalt pavements were tested during a two year skid inventory of the state highway system. With the assistance of the department's highway maintenance subdivision and regional materials engineers, coarse aggregate sources were determined for almost all asphaltic concrete pavements that had been skid tested. Surface course age was also checked, and the cumulative vehicle passes were calculated. Acid-insoluble residue tests were conducted on all geologic formations that were sources of coarse aggregate for asphaltic concrete. Carbonate staining was conducted on all limestones.

In addition, 51 experimental surfaces were placed on state highways in three regions. These contained varying quantities of hard acid-insoluble materials, and the mix types ranged from fine sheet asphalts to dense graded asphalt concrete with up to 30 percent aggregate of 1/4 inch (6 mm) to 1/2 inch (12 mm) maximum size.

Skid numbers were determined as a function of cumulative traffic in millions of vehicles per lane for pavements containing limestone coarse aggregate consisting of only minor quantities of hard sand-sized impurities (less than 10 percent acid-insoluble residue). After 10 million vehicle passes, only 10 percent of the roads containing these coarse aggregates were expected to be skid resistant.

As the hard impurities in the limestones increase, higher skid numbers are obtained. When the noncarbonate contents exceeded 15 percent, only about 10 percent of the pavements had skid numbers in the unacceptable range of the low-impurity limestones.

One of the most extensive sources of coarse aggregate in New York is the Onondaga Limestone formation which occurs in an east-west band across the state. This formation contains chert nodules (a flint-like quartz) in varying quantities: A relatively low percentage at the east end but increasing to 40 percent or more toward the west. The chert does not appear in the softer limestone matrix but rather in a variety of forms ranging from whole pieces of crushed aggregate to a small chip on the edge of a piece of limestone aggregate.

As was expected, the 93 test pavements constructed from the Onondaga formation showed a wide variation in skid numbers. This is explained by the varying amount of chert particles. The pavements with skid numbers in the same range as the pure limestones contained aggregates with less than 15 percent chert, whereas those with higher skid numbers ranged from 20 to 50 percent.

Sandstone, granite, and traprock were grouped for analysis because they are noncarbonates. The acid-insoluble residues for these aggregates ranged from 93.0 to 99.6 percent. The skid resistance of non carbonates were clearly superior even after 10 million vehicles passes.

By analyzing the long-term skid resistance of asphaltic concrete mixes in relation to the mineralogy of the coarse aggregate permitted the following classification of aggregates to be formulated:

- Carbonates with less than 10 percent sand-sized impurities,
- Mixtures of carbonate and noncarbonate aggregates with less than 20 percent noncarbonates,
- Mixtures (carbonates and noncarbonates) with more than 20 percent noncarbonates, and
- Noncarbonates, defined as any aggregate with more than 80 percent acid-insoluble residue.

Aggregates in the first two categories were judged incapable of providing long-term skid resistance (up to 10 million vehicle passes) in asphalt mixes. Aggregates in any of the other categories will produce pavements generally polish resistant throughout their lives.

Following the collection of the above information a list of coarse aggregate suppliers by type of stone being quarried was compiled.

After a thorough analysis of research data and due consideration for aggregate resources available in that state, the following specification was prepared to ensure long-term skid resistance of asphalt pavements. It applies only to the coarse aggregates used in surface course mixes where the anticipated cumulative traffic per lane during the design life of the pavement surface exceeds one million. All other department specifications governing the mixing plant, materials, and construction details remained in effect.

The new specification required that coarse aggregates be from approved sources and that they meet one of the following requirements:

- They may be limestone from the Onondaga formation, but must contain at least 20 percent chert particles;
- They may be either from a dolomite formation or from a limestone formation other than Onondaga, but they must contain at least 10 percent sand-sized acid-insoluble impurities; or
- They may be noncarbonate crushed stone such as sandstone, granite, traprock, slag, or similar materials.

Aggregates not meeting any of these requirements must be upgraded by blending them with noncarbonates. They are governed by the following requirement:

- The coarse aggregate may be a blend of carbonates (limestone or dolomites) and noncarbonates (sandstone, granite, traprock, slag, etc.) provided that 20 percent of all stone over 1/8 inch (3 mm) is noncarbonate, and that if stone over 1/4 inch (6 mm) is included, 20 percent of it is also noncarbonate.

In the final mix the total aggregate over 1/8 inch (3 mm) must have at least 20 percent noncarbonate particles. When the aggregates are from more than one source, or of more than one type of material, they must be proportioned and blended to provide a uniform mixture. If lightweight aggregate or slag is used as the noncarbonate, the requirement of 20 percent by weight must be adjusted for the different specific gravities.

SUMMARY

Durability of the skid resistant surface of a pavement depends on several factors including materials, design, construction, and traffic volumes. Even by carefully controlling these factors it is very difficult to predict the long range skid resistance of a pavement. Skid test data combined with traffic speed and volume data taken over the pavement life allows for development of optimum specifications for skid resistant surfaces. One of the objectives of skid testing should be the determination of mixes showing the highest skid resistance over the life of the mix and incorporating this data into specifications.

Laboratory tests should always be correlated with field tests before incorporating in specfications.

5101

EVALUATIONS

- Polish/Wear Resistance
  - Petrographic Analysis
  - Acid Insoluable Test
  - British Wheel Polishing Machine
  - Laboratory Tracks
  - Field Evaluation
- Macro Texture
  - Schonfeld Method
  - Sand Patch Test
  - Out Flow Meter

SESSION 52

INSTRUCTION GUIDE

EQUIPMENT - Overhead Projector

AIDS: Viewgraphs 520-520

APPROACH: Viewgraphs 5201 to 5204 can be used with pages 52-1 to 52-9 as a general introduction to critical factors in designing a good skid resistant surface.

Next discuss factors affecting PCC and Asphalt design.

Viewgraphs 5205 to 5208 can be used to complete the session as a final pulling together of the elements that affect micro and macrotexture properties in pavement surfaces.

SESSION GUIDE

SESSION: 52. DESIGN OF NEW PAVEMENTS

SESSION OBJECTIVE:

At the end of this session, participants will be able to relate skid resistance requirements to the design and construction of new pavements.

REFERENCES: 4, 55, 67, 68, 69.

CONTENT:

Introduction 52-2

Performance Criteria 52-3

Aggregates for Wear and Skid Resistant Systems 52-5

Anticipating System Requirements in Pavement Design 52-8

Design of Skid Resistant Roadways 52-8

Guidelines for Skid Resistant Pavement Design 52-12

INTRODUCTION

In the interest of highway safety, it is essential that new pavements be designed and constructed with surface characteristics adequate for minimizing wet-weather skidding and hydroplaning accidents during expected service life. Procedures for correcting worn or polished surfaces were described in previous sections.

Historically, the associated problems of pavement wear, surface polishing, slipperiness, and skidding have been with us since hard-surface pavements were first built. However, relatively speaking, problems were not serious in the early stages of vehicle and pavement development. Wear and polishing were slow processes under the extremely low traffic volumes, few heavy trucks, and low driving speeds. The consequences of skidding were not as serious because low speeds resulted in lesser impact forces in collisions. Collisions with other moving vehicles were rare because of the few vehicles on the road. Also, low braking efficiency and less advanced tire design were often the controlling factors in stopping, rather than smooth or polished pavement surfaces.

As vehicles improved, their numbers and speeds increased. Many large and heavy trucks took much of the freight formerly hauled on the railroads. With the development of hydraulic, air, and disc brakes, and with improvements in tire rubber and tread design, the condition of the pavement surface has become a more significant factor in stopping, particularly on wet pavements. Moreover, higher traffic speeds and greater traffic densities have resulted in an increase in accidents of which skidding is a significant factor.

A mounting volume of research in recent years has been directed toward delineating the mechanism of skidding. Because most pavement surfaces have adequate skid resistance when dry, such studies have usually been concerned with the interaction between tire and pavement surface in the presence of water, including the phenomenon of hydroplaning. Variables in this interaction include tire-inflation pressure, water viscosity, tire-tread geometry, initial water-film thickness, and particularly, pavement surface texture. A pavement's macrotexture (roughness as influenced by aggregate gradation, mix design, and surface finishing) determines its surface drainage characteristics, whereas its microtexture (microscopic roughness as influenced by the surface friction.

If surface drainage is poor, a localized or generally flooded pavement condition will develop, making it difficult, and in some cases impossible, to displace water from the tire-pavement interface. Consequently, friction is reduced, and, at higher speeds, hydroplaning may occur. Thus, particularly at high speeds, the ideal pavement surface should be smooth riding, well-drained, have a coarse macrotexture for efficient displacement of water, and have a sharp, gritty microtexture for high frictional characteristics.

Geometric design and mix design affecting drainage characteristics is of primary importance

For satisfactory performance, a pavement surface should retain these skid resistance characteristics for a reasonable period of exposure to traffic and environmental conditions. For asphaltic concrete pavement, skid resistance characterisitics are generally considered to be imparted primarily by the coarse aggregate component. Some aggregates, particularly certain limestones, may result in satisfactory initial skid resistance but tend rapidly to become smooth or polished under traffic. Thus it is imperative to use coarse aggregates that will withstand the polishing action of traffic. In portland cement concrete pavements, use of non-polishing, fine aggregates is important. The initial skid-resistance characteristics are provided by the mortar and fine aggregate and by the surface texturing accomplished during construction.

Wear and Polish resistance equally important for long service life.

PERFORMANCE CRITERIA

Criteria for performance of wear-resistant and skid-resistant systems should be established in relation to the following:

- Skid resistance.
- Hydroplaning potential (texture, drainage, rainfall).
- Effective life.
- Cost
- Application procedures.
- Use of available materials and equipment.

V 5201

- Maintainability.
- Riding quality.
- Tire noise.
- Tire wear.
- Appearance.

Because the criteria for systems will differ considerably depending on the requirements imposed by the combination of traffic factors, road geometrics, and the environment of a particular location, criteria should be established for more than one level. The level at which a particular section of pavement would be classified will depend on a combination of many factors, some of them not well-defined. Some of the factors that would have to be taken into consideration in classification of pavements for this purpose are: travel speeds, degree of curvature, volume of traffic, sight distance, width of lanes and shoulders, grades, amount and intensity of rainfall, presence of snow and ice, number of lanes, at grade street or railroad crossings and presence of stop signs and signals. In addition, a high accident location might also indicate a deficiency in the pavement surface.

Design considerations will depend on required service level of the pavement

One method of classification of pavements by levels of required performance of a surface system might include four categories as follows:

- Minimum - Driveways, parking lots, minor residential streets; no significant grades.
- Normal - Most city streets and rural roads; no steep grades, sharp curves, or unusual hazards.
- Special - Interstate and similar high-speed highways; steep grades, sharp curves, or other such locations in otherwise "normal" category.
- Critical - Curves on high-speed highways (requiring reduced speed); some high-speed approaches to toll plazas and to moderate-speed stopping locations such as traffic intersections and pedestrian cross-walks; long and steep downgrades

V 5202

on high-speed highways; high-speed merging or required lane-changing locations.

Criteria for skid resistance can be formulated in terms of required friction demand based on performance of aggregates and mixes. Criteria for hydroplaning potential should be expressed in terms of a measure of texture, possibly modified by terms for drainage and rainfall. Effective life, cost, application procedures, availability of materials and equipment, riding quality, tire noise, tire wear, appearance, and maintainability may be used as a basis for comparison and selection from among systems that satisfy the minimum requirements of friction demand and of texture.

AGGREGATES FOR WEAR AND SKID RESISTANT SYSTEMS

Because aggregates comprise more than 90 percent of a pavement mixture, their selection is of primary importance in the design of a wear - and skid-resistant surface. Some correlations between aggregate type and aggregate wear properties used in highway pavements carrying conventional traffic have been determined. However, the relationship of mineralogical and textural characteristics to polish wear has not been well established. Work in other countries, particularly in the British Transport and Road Research Laboratory, has provided preliminary indications regarding the choice of polish-resistant rock by petrographic classification. At least one state highway department (Texas) has developed data along similar lines.

One approach to the design of pavements for wear - and skid-resistant service would involve the selection of aggregate for the anticipated level of service on the basis of:

- Polish, abrasion, impact, and water resistance, as determined by laboratory tests that have been correlated with field performance.
- Delivered cost.

At present the only laboratory test method with a history of proven performance in providing an indication of polish wear is the Polished Stone Value (PSV). Other tests have been used successfully in measurement of abrasion, impact, and water resistance. Aggregates available for highway paving use could be characterized by a PSV and by results of tests selected as appropriate for determination of other properties. With this information, the benefit/cost relationships for aggregates available to a particular job could be determined and the aggregate with the most advantageous relationship selected.

In the absence of such information, the following preliminary guidelines have been prepared as an aid in locating potentially promising aggregates. For this purpose, aggregates have been divided into five groups according to their polish wear resistance. Aggregates in all groups would be expected to exhibit average resistance to abrasive wear by conventional traffic. Deteriorative wear by studded tires is not considered here, but is discussed briefly later.

Group I

In this group are those aggregates with outstanding ability to resist polish wear. Some of these materials are practical only for limited use in critical locations because of high cost of manufacture or transportation. They are generally a heterogeneous combination of minerals, with a coarse-grained micro-structure of hard particles bonded together by a slightly softer matrix. Aggregates in this group are corundum rich and include calcined bauxite (synthetic) and emery (natural.) Group I aggregates are typified by those developed for, or used by, the grinding-wheel industry.

Group II

This group comprises a minority of the types currently used for highway paving and provides significantly better-than-average resistance to polish wear. Synthetic aggregates in this group are some air-cooled steel blast furnace slags and some expanded, light-weight shales. Natural aggregates in this group are many of the coarse - and medium-grained sedimentary rocks, particularly, crushed sandstone, arkose, graywacke, and quartzite from formations providing good durability and abrasion resistance.

Group III

Except for those aggregates included in Groups I and II, this group consists of many of the aggregates currently used for asphaltic concrete and portland cement concrete paving. They have a satisfactory resistance to polish wear for all but the severest conditions. The natural aggregates forming this group provide "average" resistance to polish wear and include coarse-grained, dense igneous and metamorphic rocks of the granite, granite gneiss, grano-diorite, grano-diorite gneiss, diorite, and diorite gneiss types showing good integrity and an absence of pronounced foliation.

Group IV

This group comprises all remaining aggregates (excepting Group V), and may be described as exhibiting lower-than-average resistance to polish wear though still usable for paving purposes. Included in this group are the metamorphics formed from materials not inherently possessing high resistance to polish. Some representatives of the group are siltstones, arch marble, slate, graywacks, and schist.

Group V

Aggregates associated with low polish resistance comprise this group. Typical are carbonate aggregates, including most limestones and dolomites, and uncrushed, rounded, and water-worn gravels. Their use should be avoided when skid resistance and resistance to polish wear are required. Where other aggregates are limited in availability, these are often used for lower courses of pavements not exposed to traffic.

This classification may be employed as a guideline for selection of fine aggregate to produce polish-resistant portland cement concrete where the surface mortar is a more important factor in resistance to polish wear and skid resistance than is the coarse aggregate. It is the coarse aggregate that is the more important from the skid and polish standpoint for asphalt concrete, asphalt surface treatments, and similar systems.

With regard to aggregate selection in areas of exposure to studded tires, the problem of polishing usually does not arise because of the extremely severe mechanical action of the studs in roughening the surface. The main problem here is in preventing excessive degradation due to impact failure of the aggregate. No completely satisfactory solution to the problem of studded-tire wear has yet been discovered. Best resistance to such deteriorative wear would be expected to be provided by the hardest, toughest, densest aggregates available.

ANTICIPATING SYSTEM REQUIREMENTS IN PAVEMENT DESIGN

In the design of pavements, anticipated service conditions must be made in order to properly select polish-resistant materials. Several conditions representative of those that may be anticipated are:

- High Polish Wear - It is anticipated that conditions will be such that high polish wear may be expected (e.g., a high volume of heavy truck traffic or frequent braking in specific areas). A pavement surface that will resist such high polishing action should be selected.
- Moderate Polish Wear - It is anticipated that conditions will be such that polished wear may be expected, but that it will be less severe than for high polish wear. A pavement surface that will be adequate for resisting such polishing action should be selected.
- Studded-Tire Wear - It is anticipated that a high volume of studded-tire traffic may be expected. A pavement surface with maximum resistance to such wear should be selected, and be consistent with the economics of construction and maintenance.
- High-Speed Curves - It is anticipated that measures will be required to provide special wear - and skid-resistant surfaces on high-speed curves to avoid a sideways-slip condition.
- Weight Limitation - It is anticipated that special surfacing will be required to provide adequate wear and skid-resistance, with minimum addition of dead load to structures such as bridges. (55)

V 5203

DESIGN OF SKID-RESISTANT ROADWAYS

Achieving a skid resistant surface is only one of many objectives in pavement design

A primary factor in achieving a skid resistant roadway is the design of the pavement wearing course. The necessity of achieving a skid resistant surface is just one of a number of factors that must be considered by the designer. Some of the other factors include:

- Smooth riding qualities.
- Ability to limit excessive tire wear and noise.
- Structural stability to withstand forces imposed by maneuvers of vehicles, environment, etc.
- Exhibition of desirable qualities for day and night driving under changing environmental conditions.

V 5204

The attainment of these properties is dependent upon the careful selection of aggregate properties, selection of the bonding agent, and the interaction of all components in the mixture. The design of several listed types of surfaces follows:

- Portland Cement Concrete
- Asphalt Concrete
    - a. Continuous Grading
    - b. Gap-Graded or Continuous Grading Mixture with Special Aggregate Additions to Surface
    - c. Open-Graded
    - d. Sand Asphalt
- Slurry Seal Coats
- Aggregate Seal Coats (4)

In general, mixes should be designed so that losses in skid resistance during the design life do not exceed about fifteen skid numbers. For high volume traffic conditions, it is desirable to use mix designs and aggregates which will result in wear factors below .05. Conditions of high traffic volumes, high operating speeds, and large percentages of wet weather time will justify the provision of higher skid resistance and lower wear factors that result in better retention of high skid resistance.

Low traffic volumes, and small percentages of wet weather time may justify the allowance of a higher wear factor and a possible subsequent loss of skid resistance. However, polishing has been found to be less severe for a given number of passes spread over a number of years than it is for the same number of passes occurring in one year. Therefore, an aggregate which would polish rapidly under heavy traffic volumes may provide a relatively high level of skid resistance throughout the life of the surface on a low traffic volume road.

The wear factor as used here is an indicator of the loss of skid resistance of the total mix with traffic exposure. It will be affected by the properties of the total mix rather than the aggregate alone. Wear factor is also dependent on the speed at which the skid number is measured. A stable mix or a durable surface which does not consolidate or wear under traffic will exhibit a much better wear factor at high speeds because of its ability to retain its initial speed gradient and its resistance to flushing.

Portland Cement Concrete

Longitudinal grooving, while not necessarily producing a large increase in skid resistance as conventionally measured, has been very effective in reducing high speed accidents, with very dramatic reductions obtained on curves with high initial wet weather accident rates. Longitudinal grooving has also been effective in accident reduction on tangent sections. This suggests that longitudinal texturing may provide high friction perpendicular to the direction of travel (which would not be indicated by conventional skid testing procedures) enabling retention of vehicle directional control.

Transverse texturing will produce higher skid numbers than longitudinal texturing as measured by the skid trailer for a given amount of texture. This may not, however, necessarily indicate a better or equivalent friction condition as related to accidents. The ability of either longitudinal or transverse texturing to prevent water pressure buildup between the tire and the wet pavement surface, as indicated by the speed gradient, will depend on the texture depth, width, and number of impressions. The "large" drainage channels provided by either longitudinal or transverse grooving are very effective in this respect. This drainage ability at least partially explains the effectiveness of grooving in accident reduction. Transverse texturing aids in surface runoff resulting in less wet pavement time. Transverse tining is the recommended procedure on new concrete pavements.

Combinations of longitudinal and transverse texturing of sufficient depth and width to provide adequate drainage both from between the tire and pavement surface and from the pavement surface itself provide the most desirable surface for high speed conditions. Approaches to at-grade intersections on high speed facilities, or other special conditions requiring severe braking from high speed may require heavy transverse texturing, combinations of longitudinal and transverse texturing or other special treatment.

The inclusion of a good skid resistant aggregate (hard, sharp particles) and a low water cement ratio at the surface are essential for good skid resistance and durability. Overworking of the surface and the addition of water in the finishing operation will reduce durability and should not be allowed. When evaluating the adequacy of the surface for the design period the predicted loss in skid resistance and texture depth, based on anticipated traffic and the surface durability, should be considered.

In a portland cement concrete pavement surface, the necessary surface voids must be initially produced by proper texturing. A positive texturing method, capable of consistently producing textures of known quality should be specified. Wire brooming is more consistent in producing positive texture than is the burlap drag. However, the sharp projections produced are subject to rapid wear under traffic, especially if the surface durability is poor. Grooves produced in the plastic concrete by fluted floats and combs have been reported to be more resistant to wear than the finer textures produced by the burlap or broom.

Guidelines for skid resistant concrete pavement construction have been recently drafted by joint AASHTO-ARBA-AGC Task Force Number 15. These Guidelines (67) present the latest practical state of the art.

GUIDELINES FOR SKID RESISTANT PAVEMENT DESIGN

Many factors affect the skid resistance of concrete pavement.(68) Among the most important factors are the fine texture (grittiness) of the surface, contributed by the fine aggregate, and the coarse texture formed by the method of finishing. The durability of the surface texture is a function of the wear-resistant qualities of the concrete and the character and volume of the traffic.

Mix Design

Mix design formulation for concrete pavements should consider the quality and durability required to produce and retain good textures, during and following construction. The design of quality concrete mixes is adequately covered in current publications, bulletins, and specifications as issued by the Portland Cement Association, Federal Highway Administration, Federal Aviation Administration, American Concrete Institue and American Association of State Highway and Transportation Officials, as well as many other trade associations and state and federal agencies. Research previously referred to (68), has shown that, to obtain better wear resistance in the pavement surface, special consideration must be given to the following factors:

- Wear resistance of concrete increases as the cement factor is increased.
- Wear resistance of concrete increases as the water-cement ratio is decreased.

A review and study of this information will indicate that, when designing a concrete mix for a pavement which will carry high volumes of traffic, or involve conditions that will subject the surface to highly abrasive action, the water-cement ratio should be lower (0.50 or less) than normally required for adequate durability under less severe conditions.

To provide good skid resistance, the proportion of fine aggregate in the concrete mix should be near the upper limit of the range that permits proper placing, finishing, and texturing. The sand content should provide an adequate amount of mortar for proper surface texturing without the addition of water or excessive manipulation.

Air Entrainment

Entrained air should be used in all concrete pavements because of the beneficial effects to both plastic and hardened concrete. An important benefit is to protect the textured surface of the pavement from the effects of alternate cycles of freezing and thawing and the application of deicing salts. Air entrainment also improves concrete in the plastic state by:

- Reducing segregation when hauling in nonagitating conveyances and during placing operations.
- Increasing workability.
- Reducing bleeding.
- Reducing the amount of water required for satisfactory workability.

Each of these factors contributes to the production of an adequate and durable surface texture.

The amount of entrained air needed to produce durable concrete varies with the maximum size coarse aggregate. The Joint Task Force (69) recommends the grading be within the following ranges:

Maximum Size of Coarse Aggregate, Inches	Air Content, Percent by Volume
1-1/2, 2, or 2-1/2	5 ± 1
3/4 or 1	6 ± 1
3/8 or 1/2	7-1/2 ± 1

When entrained air is not required for protection against freeze-thaw or deicers, these air contents may be reduced by about one-third, while still obtaining the other benefits of air entrainment.

Aggregates

Where abrasion-resistant aggregates are not economically available, locally available aggregates with relatively low resistance to polishing may be used in the bottom layer of pavement. More expensive, hard, and angular polish resistant aggregates would be required in a relatively thin surface course to be placed while the lower course concrete is still plastic. While this is not yet a common practice in this country, it is expected to be used more often as high quality aggregates become more scarce. This practice is in wide use in Europe.

Fine Aggregate - Research to date indicates that the siliceous particle content of the fine aggregate as determined by the acid insoluble residue test should not be less than 25 percent.(69) The siliceous particle content is very important, and where economically feasible, a higher percentage should be required. Where suitable materials conforming to these requirements are not economically available, alternate methods of achieving a skid-resistant surface should be investigated. These might include blending of fine (natural) aggregates with synthetic aggregates or applying wear-resistant particles to the surface of the fresh concrete.

Coarse Aggregate - Coarse aggregate will not affect the initial skid resistance of concrete pavement, but will affect it if the pavement becomes exposed due to surface wear. The performance record of the coarse aggregate under consideration should be evaluated in terms of skid resistance.

Asphalt Concrete - For high speed operations, bituminous surfaces with a relatively high percentage of larger size aggregate (+ 1/4 inch sieve) are required to provide the necessary surface voids. Voids are created by the provision of a high percentange of one-sized coarse aggregate. A reduction in the percentage of the one-sized aggregate either by an increase in the percentage of material smaller than the one-sized aggregate or by an increase in the percentage of materials larger than the one-sized aggregate will result in a reduction in surface voids. On surfaces which have the necessary voids for high speed operations the tire of a vehicle will be primarily in contact with the coarse aggregate. The frictional properties of the coarse aggregate will, therefore, determine the skid resistance properties of a properly designed surface for high speed traffic.

When small size material is incorporated in the mix, the relative area of coarse aggregate at the pavement surface (that contact with the tire) is reduced, which will result in a loss of effectiveness of the skid resistance properties of the coarse aggregate. Mixes capable of resisting consolidation under traffic are necessary to prevent loss in skid resistance. Consolidation further reduces the surface area of the coarse aggregate exposed, and increases the loss of coarse texture.

Mixes with adequate surface voids and high resistance to consolidation, or with sufficient initial voids to tolerate consolidation without detrimental effects on skid resistance and texture, normally require either a high proportion of one-sized coarse aggregate or an asphalt content that is so low that the mix may have poor durability. A surface course composed of as large an amount of high quality one-sized coarse aggregate as feasible, therefore, is desirable for high speed, high traffic volume conditions.

Very good surface void and skid resistance properties can be achieved with a plant mixed surface course, using a large percentage (about 60 percent) of one-sized coarse aggregate 3/8 to No. 4 sieve) limiting the amount of material on the smaller sieve sizes (maximum about 15 percent minus No. 8 sieve) and a high asphalt content (6-7 percent). These surfaces, known as open graded plant mix surface courses, also have superior riding qualities and greatly reduce spray from truck and automobile tires that obstruct the vision of passing vehicles.

The use of a substantial percentage of large size aggregate (3/4 inch or larger) or a surface treatment (chip seal) may produce the desired surface voids but may result in objectionable riding and noise qualitites.

The properties required for good skid resistance at the surface may be distinct from, and in the case of high voids, may be directly opposed to, those desired in the structural mat. Specific designs and specifications for surface courses independent of the structural requirements of the mat are required. The use of relatively small quantities of high quality material specifically chosen for surface conditions is feasible and should be practiced.

The use of special aggregates, even though considerably more expensive than locally available natural materials, may be necessary to produce the needed skid resistance qualities. The use of relatively small amounts of high quality material in a thin surface course may be cost effective, particularly at critical highway locations, and the use of these surfaces as part of initial construction is encouraged.

After consideration of local material availability and environmental conditions, the designer must establish the tire-pavement friction need primarily on the traffic speed. As previously mentioned, a certain degree of microtexture is always needed for both low and high speed traffic; however, high speed traffic requires, in addition, an adequate macrotexture for rapid drainage.

There are a number of different types of asphalt concrete and surface treatments involving asphalt as a binder. Therefore, the designer has much flexibility when working with surface types containing asphalt as a binder. However, the designer must keep in mind that the choice of a surface type in terms of skid resistance must be balanced with other important factors such as availability and characteristics of local materials, climate, traffic and other factors.

The designer must select his aggregates to provide sufficient microtexture as well as a proper choice of crushed particles and gradation to insure adequate macrotexture. Generally, aggregates fitting the selected requirements, if exhibiting resistance to wear and polish, will also aid in providing sufficient stability to the pavement. Presently used mix designs such as the Hveem and Marshall methods may be used to obtain the desired asphalt content. The determination of the optimum asphalt content is a very critical design decision, not only for pavement skid resistance, but also for structural adequacy. An excess of asphalt cement in any pavement type or surface treatment may rapidly lead to "bleeding" or a "flushed" surface, one of the most serious wet weather skid hazards and a very difficult maintenance problem.

As discussed previously polish resistant aggregates may be scarce in some areas. Under these circumstances, skid resistant mixes may be designed by blending imported coarse polish resistant aggregate with polish susceptible fines. Presently, knowledge is limited concerning the percentages to be used in the blend.

Another excellent anti-skid pavement is now known as an open-graded friction course (previously discussed). This mix contains about 30-40 percent voids and has a high film thickness. The voids and heavy texture created by a coarse grading provide an excellent nonskid surface. Both surface drainage and subsurface porosity are provided so as to drain surface water away rapidly. If the aggregate properties, gradation and asphalt content are properly selected, the resulting mix will not only provide microtexture but, of great importance, outstanding macrotexture. Its performance for high speed highways has been excellent.

The designer must be aware of certain overall requirements for open-graded pavement mixtures. Since this type of pavement permits very rapid downward movement of water, the underlying pavement must be impermeable in order to prevent entrance of free water into the structural section. Cross-slope must be sufficient to allow rapid movement of water through the open-graded surface onto the adjacent shoulder. This is of special importance in hilly terrain where rapid longitudinal flow of water through an open graded surface may build up water above the surface in swales, creating a severe hydroplaning situation at these locations.

Another method that may be used in this situation is a sprinkle treatment (previously discussed). In this case, one may design a continuously graded mix containing a polish susceptible coarse aggregate and, following laydown and prior to rolling, sprinkle the surface with 3-7 pounds/sq. yd. of a polish resistant precoated coarse aggregate. This method has also been used for a number of years in England where very dense mixes, gap-graded, high in sand are laid. These mixes have a very smooth surface, so they are finished with a sprinkle treatment. The designer should be aware that the two designs relative to the application of surface aggregates are for meeting the same criteria, but should be selected on a different basis. In the first system, the surface aggregate is for the purpose of preventing rapid polish of the coarse aggregate in the mixture. In the second case, the purpose is not only to provide a drainage system, since the underlying mix within itself will produce a smooth rolled surface.

5201

EVALUATION CONSIDERATIONS

- Skid Resistance
- Effective Life
- Cost
- Maintainability
- Ride Quality
- Structural Capacity
- Noise

5202

SKID RESISTANCE NEEDS

CRITICAL - High Speed Curves, Toll Gate Approaches, Intersections

SPECIAL - High Speed Highways, Interstates

NORMAL - City Streets, Rural Roads

MINIMUM - Driveways, Parking Lots, Residential Streets

5203

SERVICE CONSIDERATIONS

- High Polish Wear
- Moderate Polish Wear
- Studded Tire Wear
- High-Speed Curves
- Weight Limitations
- Geometrics

5204

DESIGN FACTORS

- Skid Resistance
- Smooth Ride
- Limit Tire Wear and Noise
- Structural Stability
- Day/Night/ Environmental Conditions

5205

DESIGN DECISION

Reduce Friction Demand?

OR

Increase Friction Supply?

5206

ACHIEVING MACROTEXTURE

- Proper Aggregates
- Surface Treatment
- Open Graded Mix
- Texturing PC Concrete

5207

ACHIEVING MICROTEXTURE -

BITUMINOUS PAVEMENTS

- Non-polishing Aggregates
- Sprinkle Treatment
- Silica Sand Mix (low speed)
- Synthetic Aggregates
- Surface Treatments

5208

ACHIEVING MICROTEXTURE -

PORTLAND CEMENT PAVEMENTS

- Control Cement Factor
- Control Water-Cement Ratio
- Gritty Finish

SESSION 53

INSTRUCTION GUIDE

EQUIPMENT - Slide Projector

AIDS: Slides 5301 to 5314 listed in Teaching Aid 5301

APPROACH: Pages 53-1 to 53-8 give a background of development of texturing methods leading to FHWA T.A. 5140.10.

This technical advisory is reproduced in part as the recommended practice on pages 53-8 to 53-10.

Finally other texturing methods that have been used are discussed briefly.

The slides may be shown at the end of the session but should be referred to during the session.

SESSION 53

AID: 5301
SLIDES

5301. Longitudinal Grooving

5302. Close Up of Longitudinal Grooves

5303. Spacing of Longitudinal Grooves

5304. Transverse Grooves

5305. Longitudinal and Transverse

5306. Longitudinal and Transverse at Other Spacings

5306A. Longitudinal and Transverse at Close Spacing

5307. Dimpling Method

5308. Results of Dimpling

5309. Alternative Dimpling/Tines

5309A. Alternative Dimpling/Tines

5311. Sprinkled Aggregate (Hand Sprinkled)

5311A. Close-up Aggregate (Hand Sprinkled)

SESSION GUIDE

SESSION: 53. TEXTURING NEW PAVEMENTS: GROOVING, METAL TINES, BURLAP DRAG, WASHING AWAY MORTAR, AND BRUSHING

SESSION OBJECTIVES:

In this session participants will learn methods used to texture new portland cement concrete pavements.

REFERENCES: 68, 70, 71, 72, 73, 74, 75.

CONTENT:

Introduction 53-2

Finish With Burlap Drag 53-2

Texturing of Concrete with Metal Tines 53-6

FHWA Technical Advisory T 5140.10 53-8

Texturing of PCC Pavement Surfaces - Discussion 53-10

Other Textures 53-12

INTRODUCTION

The skid resistance of pavements, as previously discussed, is a function of surface texture. Skid resistance at low speeds is determined by microtexture and at higher speeds by both microtexture and macrotexture. If both a high level of microtexture and macrotexture is built into pavements it is still necessary to have proper drainage so the texture asperities can maintain constant contact at the pavement-tire interface. A lack of proper drainage will largely nullify pavement texture and produce a situation conducive to hydroplaning.

Finishing of concrete pavements, the process by which the pavement texture is incorporated into the surface, was generally accomplished until recently using a burlap drag, a broom or a belt. In 1963, approximately 60 percent of the highway departments used a burlap drag, 12 percent specified either a burlap drag or a broom, 8 percent a combination of broom and burlap drag, 6 percent a belt, 6 percent a broom, and the remainder specified that either a belt or a burlap drag could be used.(68)

FINISH WITH A BURLAP DRAG

Until the increase in traffic volumes and speed limits which accompanied the building of the interstate systems, states had experienced little difficulty with skid resistance on portland cement concrete (PCC) pavements. The finish was typically with a burlap drag.

The burlap drag method of finishing (texturing) portland cement concrete pavement gives a uniform texture. The texture as implied by the name is imparted to the pavement surfaces by dragging wetted burlap on the pavement surface somewhere in the paving train. Exactly where the drag is hung is not important but is usually placed at the rear of the combination float finisher, on a traveling bridge following the straight-edge operation or mounted on a self propelled machine at the rear of the paving train.

Durability of finish by burlap drag is greatest drawback.

It became apparent to several states at approximately the same time that the burlap drag texturing method being used was not imparting a texture durable enough to last the service life of the pavement. This was showing up as a relatively high percentage of wet pavement accidents on some

PCC interstate highways. Also the measured skid numbers were low and this combined with the rather smooth pavement surfaces and thick water films presented a potential for hydroplaning.

The first attempts to impart a coarser texture to pavements was a variation of the burlap drag method. This was done by using a number of burlap passes.

Attempts to impart coarser texture to improve durability.

On a project in Virginia a harsh texture was applied to the I-64 bypass around Charlottesville.(70) The project personnel had the sample texture block for comparison purposes.

The texture was placed in the following manner:

In the paving operations, a slip-form paver placed and screeded the full 7.3 m (24 ft.) pavement width in one pass and a tube float applied the initial finish. The float unit was equipped with a hydraulic mechanism carrying the burlap drag used to apply the final finish. Following the float was a curing unit that applied either polyethelene sheeting or a liquid membrane. All units in the paving train were remotely controlled transversely by a guideline placed on the edge of the roadway.

Several attempts were necessary before a texture of the desired harshness was achieved with the burlap drag. Success was achieved with one to four passes of the drag - depending upon the consistency of the concrete, the rate of surface drying, and the number of layers of burlap used. Project personnel were required to exercise a good deal of judgement in determining the number of passes to apply under given circumstances. On long sections of pavement, drags consisting of two layers, two or three layers, and four layers of burlap were tried. A four-layer drag with the necessary number of passes was finally determined to be the most effective procedure.

Other factors affecting the texturing procedure were the length of the trailing burlap cords and the condition of the burlap. Trailing cords of 100 mm to 150 mm (4 in. to 6 in.) in length were helpful, while burlap that had accumulated some mortar through use was found to be effective. Again, the judgement of project personnel in applying the proper number of passes was relied upon.

The major technical problems encountered with the heavy burlap texturing were failure to achieve the desired texture because of late application of the burlap drag, and obliteration of the texture by the polyethelene sheeting used for curing purposes under certain circumstances.

The first of these problems was eliminated easily through close attention to the time of texturing to ensure that the burlap drag was applied well before the pavement surface had achieved any significant degree of set. In fact, the concrete used in the slip-form paving operation was very uniform and necessarily of such a consistency that texturing was possible immediately after floating.

The second problem was solved by using a liquid membrane curing compound in lieu of the polyethelene sheeting. The curing compound was applied approximately at the time the sheen disappeared from the concrete surface so that the texture was not affected by the curing operation. Subsequently, polyethelene sheeting was used only in special cases, such as when it became necessary to protect the surface from heavy rains or during extremely cold weather. In the latter case, the sheeting was not applied until there was no danger of damage to the texture.

The burlap textured pavement was opened to traffic in September 1970. Road roughness tests conducted in the fall of 1970 dispelled suspicions that the pavement would provide a rough ride. Measured roughness values showed that two of the three contracts resulted in the best riding concrete pavements ever tested in the state. The results of these tests are included in Table 53-1, where BPR roughness values are given for each of the three textured projects along with comparative rigid pavement roughness data for the 1965 - 1969 construction seasons. It can be seen that even the roughest of the textured projects is toward the low side of average roughness values for pavements built during the previous five-year period.

TABLE 53-1

TEXTURED PAVEMENT ROUGHNESS

(1.6 km = 1 mi.)

Project No.	Length (km)	Average* BPR Roughness Units/km
1	16.4	40
2	14.8	46
3	13.7	57

* Average roughness of 25 projects constructed during 1965 - 1969 is 61 units/km with a range of 54-88 units/km.

Psychological impact of textured surfaces

It was initially concluded that some public reaction over poor riding quality was psychologically rooted in the appearance of the texture rather than in actual roughness. There were also a few adverse public reactions concerning occasional waviness of striations caused by side sway in the hydraulic arms carrying the burlap and the flexibility of the burlap material.

While the burlap texture seemed satisfactory at the time the pavement was opened to traffic, after it was in service some eight months under a traffic volume of 8,000 AVD there was a significant degree of wear in the wheel paths. This wear was easily discernible from a moving automobile and seemed to be reasonably uniform throughout the pavement sections. It was noted that the loss of texture was inversely related to the initial harshness of texture. Thus, it was believed that pavements having a heavier initial texture would retain their texture longer. This tentative conclusion seems to have been borne out by the pavement's performance over the five years since the earlier observations and by laboratory studies.

Rate of wear of texture not solved

The relatively rapid wear of the texture caused concern, and the consensus was that the limited area between the asperities tended to make the asperities weak and subject to damage through the abrasive action of vehicle tires, including a small percentage of studded tires. As indicated, reduction in the rate of wear with time was believed to result when the sharp points abraded to leave the broader and stronger remains of the asperities. In addition, it was felt that the burlap finish did not provide sufficient channels for water drainage.

John Dixon (71) reported a similar experiment in Ohio where texture was imparted by several drags being employed in the paving train. One was hung from the rear of the combination float finisher. Another was installed on a traveling bridge following the straightedge operations. The last drag was mounted on a self-propelled machine capable of fast travel in both forward and reverse directions. Four thicknesses of burlap were used, and the machine made three or four passes to obtain deep longitudional striations.

Sabey (72) found in his experiment that to hold the reduction of skid numbers to 25 percent as speeds increased from 30 to 80 mph (48 to 130 km/hr) that a texture depth of 0.025 in. (0.6 mm) was necessary. It is possible to barely obtain this depth with a heavy burlap finish but this coupled with early wear caused researchers to continue on with their search for better PCC textures.

TEXTURING OF CONCRETE WITH METAL TINES

Grooving had been performed on concrete pavements at accident prone locations with resulting improvements in safety and better surface durability. It was therefore a natural evolution for researchers to consider longitudional and transverse striations similar to grooves in plastic concrete using metal tines. A number of studies have been performed using metal tines. (70, 72, 73)

Experimentation has been with wire combs consisting of different width metal tines on different centers. On one project (70) the experiment was begun with a wire comb consisting of 1/8-inch (3.2 mm) wide metal tines on 1/8-inch (3.2 mm) centers. The tines were about 4 inch (100 mm) long. This arrangement did not produce a satisfactory land area, and it tended to displace an excessive amount of mortar. After a short distance of construction a change was effected to a 1/8-inch (3.2 mm) wide tine mounted on 3/8-inch (9.5 mm) centers. These tines were about 7-inch (180 mm). The tines were secured in wooden heads similar to the common rectangular push broom head. They were dragged through the fresh concrete with approximately 1 inch (25 mm) of the tine being parallel to the pavement surface. As the tine width wore to about 1/16 inch (1.6 mm), it became necessary to clip the ends to maintain the original width.

From the construction standpoint, the second arrangement was much more satisfactory, but it was felt that insufficient land area was being produced. After limited operation, the contractor was requested to bend up every other tine, which provided groove spacings on approximately 3/4 inch (19 mm) centers. This pattern proved satisfactory and was used on the remainder of the project.

California (74) experimented with steel tine surface textures and found that burlap or broom texturing followed by the application of steel tines for the purpose of imparting a groove with appreciable depth offers a texture of improved durability. After the microtexture is worn away, the grooves remain to provide escape routes for water between a tire and the pavement surface.

The question of whether pavement grooves should be oriented longitudinally or transversely has been controversial. There are advantages and disadvantages for each and a clear superiority for either has not been established. Transverse tine texturing offers the advantage of reduced stopping distances and rapid removal of rain water from the pavement surface. A greater tire noise is generated and there is among some highway engineers the belief that wear rates are higher. Construction is somewhat more complicated by equipment requirements and by coordinating the tining with paving progress on hot dry days.

Refer to session 42 for discussion on longitudinal versus transverse grooving

Longitudinal tine texturing imparts a "tracking" effect to the pavement surface by providing resistance to lateral movement. The ability of longitudinal diamond grooving to reduce accidents is well established. There is no reason to believe that the grooves resulting from steel tines on new construction will not be equally successful as long as some groove depth remains.

As a result of the research California developed a standard specification that calls for longitudinal texturing with initial burlap or broom drag, followed by a steel tine comb device to impart deeper grooves on PCC paving projects.

From these and other studies the FHWA developed technical advisory T 5140.10 entitled "Texturing and Skid Resistance of Concrete Pavements and Bridge Decks."(75) The purpose, background, recommendations and discussion of that advisory follow.

Purpose

To issue guidance for providing an adequate level of wet pavement skid resistance on portland cement concrete (PCC) pavement surfaces and plain or latex modified concrete bridge deck surfaces.

Background

If a pavement or bridge deck surface is to provide adequate skid resistance for high speed traffic, two important, and to some extent independent, requirements must be satisfied. First, the pavement surface must provide for adequate adhesion between the tire and the pavement under wet weather conditions. Second, the pavement surface must provide sufficient surface texture and drainage potential to prevent the buildup of water pressure at the tire-pavement interface. On PCC riding surfaces, this drainage potential can be provided initially by the texturing of the concrete surface. The adhesion component of skid resistance is dependent on the wear and polish resistance characteristics of the aggregates.

A concrete finishing procedure that will provide an adequate and durable skid resistant surface texture is needed on all pavement and bridge deck surfaces.

While a skid resistant surface texture is needed on all pavement surfaces, the need may be especially critical on bridge decks because of the limited recovery area available to out-of-control vehicles.

Recommendations

A burlap drag finish should not be used as the sole means of providing surface texture on projects with design speeds of 40 miles per hour (65 km per hour) or greater.

A broom or artificial grass drag finish, while often producing good initial surface texture, may not be durable unless a deep texture is produced by heavy bristles and high pressures. When a broom, artificial grass drag, or similar finish is specified for use on projects with design speeds of 40 miles per hour (65 km per hour) or greater, specifications that will insure a deep, durable texture must be used. Also, it should be conclusively demonstrated that safe, durable surfaces can be consistently produced by finishes before they are utilized extensively on high speed highways.

Metal tines, when preceded by a burlap or other type of drag finish, are recommended as being the most practical and dependable method of providing positive texture in PCC surfaces. The use of other procedures and equipment that will provide a similar grooved pavement surface is also encouraged.

Problems with concrete cover to reinforcement - particularly on bridge decks

The use of a deep surface texture on bridge decks may warrant increased concrete cover over the top layer of reinforcement steel beyond the 2.5 inches (63 mm) required for minimum design cover and construction tolerance. The use of heavy transverse textures may also increase the concentration of deicing salts along the curb line unless proper provisions are made to drain these areas. The last 12 inches (300mm) of deck next to the curb should be left untextured to facilitate drainage.

Special techniques may be required in order to produce a durable grooved finish on latex modified and other low water-cement ratio bridge deck surfaces. The use of flexible tines on such surfaces frequently fails to produce a groove depth sufficient for reasonable durability. In at least one state, satisfactory grooves have been produced in these dense surfaces through the use of a roller consisting of sharpened flat washers welded at intervals onto the outside of a weighted section of pipe. Other techniques may also prove to be successful. As is the case with pavement surfaces, it is normally desirable that the plastic grooving application be preceded by a burlap or other drag finish or a light broom finish.

Regardless of the finishing or texturing method used, adequate durable skid resistance characteristics cannot be attained unless the fine aggregate has suitable wear and polish resistance characteristics. Research conducted by the Portland Cement Association indicates that the siliceous particle content of the fine aggregate should not be less than 25 percent. If past experience indicates that the coarse aggregates will be exposed by surface wear and have a significant effect on the skid resistance of the pavement, they, too, should have suitable polish resistance characteristics. Crushed material will normally provide higher skid resistance than uncrushed gravels.

TEXTURING OF PCC PAVEMENT SURFACES - DISCUSSION

Transverse grooving will assist in providing a pavement surface with good durable pavement skid resistance characteristics at high speeds, will reduce splash and spray and headlight glare from wet roadway surfaces, and will continue to facilitate surface drainage until the depth of the wheel path ruts exceeds the depth of the grooves. Longitudinal grooving assists vehicle control at curves and sites involving lateral movements. Both types of grooving effectively reduce the hydroplaning potential. The longitudinal grooving of existing pavements, while not necessarily producing an improvement in skid number, has been found to be an effective means of reducing accidents at sites having high, wet weather accident rates.

Transverse grooves considered best for new pavement

Although longitudinal grooving may be preferable under some circumstances, and particularly when dealing with existing pavements, transverse grooving is considered to be superior to longitudinal grooving for general use on new construction because of the improved pavement drainage provided. Also, with the increased use of smaller, lighter cars and radial tires, complaints of vehicle handling problems on longitudinal grooved pavements seem to be on the increase.

From the standpoint of compatibility between tire tread designs and pavement texture, it is desirable that, to the extent practical, longitudinal grooving patterns be standardized. The use of 0.095-inch (2.4mm) wide grooves spaced on 3/4-inch (19 mm) centers is recommended. There is insufficient information available on which to base recommendations regarding the optimum texture for a milled PCC pavement riding surface. Some extremely harsh milled surfaces may be unacceptable for use as a riding surface.

The use of tines 0.03 inches (0.8mm) thick, 0.08 inches (2.0mm) wide, and 4 to 6 inches (100 to 150mm) in length has resulted in good, durable surfaces when the grooves were constructed to the maximum depth practical. This maximum practical depth, which will vary depending on the concrete mix design and other factors, is normally in the 1/8-inch (3mm) to 3/16-inch (5mm) range. Average transverse groove spacings of approximately 1/2 to 3/4 inch (13-20mm) are recommended. Groove spacings of less than 1/2 inch (13mm) may not have adequate durability. An increase in average groove spacing beyond 3/4 inch (20mm) cannot be expected to increase durability by a significant amount and may lead to noise problems. Relatively uniform groove spacings of 1 inch and 1 1/2 inches (25 and 38 mm) have in some instances been considered unacceptable because of the concentration of tire-pavement noise into an objectionable frequency band. Experience with average groove spacings exceeding 1-1/2 inches (38 mm) is too limited to facilitate the drawing of any conclusions. The use of wider, deeper grooves can be expected to increase the absolute noise level by a significant amount. Randomization of the groove spacing, which may result to some extent from the flexibility of the tines, is considered desirable from the noise standpoint.

The optimum length and angle of the tines will be dependent on the mix design, the weather, the finishing operations, and the stiffness of the tines and may be expected to vary somewhat from project to project.

The timing of the plastic texturing operation is critical. If performed too early, the grooves may close. If performed too late, the groove depth will be reduced. The optimum time for performing the plastic grooving operation will be dependent on many variables which are subject to rapid fluctuations.

When a tine finish is utilized, care should be exercised to avoid overlaps in the texturing operations. The overlaps will result in weak areas which will wear faster than the normal texture. For the best initial surface texture, a tine finish should be preceded by a burlap or artificial grass drag finish.

Because of the increased surface area, deeply textured surfaces will require a heavier than normal application of curing compound.

A tire tread depth gauge may be used to measure groove depths both in hardened and plastic concrete. When measuring the depth of fresh grooves formed by the tining of plastic concrete, it must be recognized that an artificially high reading may be obtained that will not be representative of the actual groove depths existing after a few months exposure to traffic. To insure that the tined grooves will be durable and effective, it is essential that they be made as deep as practical during construction.

OTHER TEXTURES

There have been a large number of experiments with textures other than those discussed. Some of these methods show promise. A listing of several of these follows:

- Combination of longitudinal and transverse situations.
- Exposed Aggregate
- Sprinkled Aggregate
- Dimpled (Imprinted)

Construction of these textures may vary. The placing of a combination of longitudinal and transverse striations may utilize the same equipment as that used for individual grooving such as metal tines.

The exposed aggregate surface may be produced by spraying the finished concrete with approximately 7 gallons per square yard of a commercial retarder, and water mixed at a ratio of 5:3 by volume. By allowing the retarding mixture to stand overnight, the mortar can be washed from the surface the day following placement.

A sprinkled aggregate surface may be obtained by hand distributing the aggregate over the surface of the plastic concrete at 5 pounds per square yard or greater. The aggregate is precoated with a cement and water paste and rolled into the finished surface of the plastic concrete.

The dimpled texturing may be imparted to the surface of the road by mounting properly spaced chloroprene blocks to a 12-inch diameter steel drum and rolling it on the pavement surface to produce the dimpled texture.

[redacted]

Skid tests have shown that all of the textures discussed in this chapter produce acceptable skid resistance except dimpled and burlapped. Transverse grooving aids in drainage more than the other textures.

SESSION 61

INSTRUCTION GUIDE

EQUIPMENT: Overhead projector

AIDS: Viewgraphs 6101-6106

APPROACH

Attempt to ascertain before the session begins where the state to which the course is given stands with respect to sovereign immunity and legislation related to agency and personal tort liability. A state-by-state summary is included as A-6108.

Recognize that the laws regarding tort liability are state statutes and that the session notes were prepared for use throughout the country.

Do not dwell upon sovereign immunity unless the state maintains such immunity. If it does, then emphasize that such immunity is being erroded, both by legislation and judicial action.

Make it clear that you are attempting to provide an overview of the situation by making certain generalizations. Many of the questions that may arise can only be answered by a specific judge and jury which will be called upon to handle the case.

Ask the participants if they have been involved in any tort liability cases or named in suits. If so, bring their experience into the discussion in order to relate to the participants' local situation.

In reviewing the basis for tort actions, illustrate the conduct expected of people responsible for highway maintenance and relate it to the conduct of the prudent man.

Numerous court cases are described in the text and Aids for this session. These examples are available to emphasize the points to be made and/or for responding to questions from the class.

EMPHASIS

Make the point that tort liability actions are increasing in number and the judgments made against highway agencies are large, many in excess of one million dollars.

Emphasize the actions that participants should take to protect their agencies and themselves from legal suits.

SESSION GUIDE

SESSION TITLE: 61. LEGAL IMPLICATIONS OF HIGHWAY SKID RESISTANCE

SESSION OBJECTIVE:

At the end of the session, participants will be aware of the potential legal liability that may arise from skidding accidents. They will also be knowledgeable on the type situations most likely to be considered negligent by the judicial authority.

REFERENCES: 76, 77, 78

CONTENT:

Responsibility

Immunity

Bases for Court Actions

Negligence

Liability

Protection from Liability

TEACHING AIDS:

A-6101. Responsibility
A-6102. Immunity
A-6103. Standard of Care
A-6104. Nuisance
A-6105. Negligence
A-6106. Employee Liability for Negligence
A-6107. Protection from Liability
A-6108. Status of the Doctrine of Sovereign Immunity by State

RESPONSIBILITY

Duties of Highway Agencies

Generally speaking, highway agencies are required only to exercise reasonable care to make and keep roads in a reasonably safe condition for the reasonably prudent traveler. Although a person is required to use reasonable care for his own safety, he is neither required, nor expected to search for obstructions or dangers.(79)

Although there is no duty to make the roads absolutely safe, a motorist using a public highway has the right to presume that the road is safe for the usual and ordinary traffic. He is not required to anticipate extraordinary danger, or obstructions to which his attention has not been directed.

Also inherent in the duty of ordinary care is the duty to eliminate hazardous conditions. Prior to elimination of those conditions, there exists a duty to post adequate warnings.

Case Study - Duty to Correct Hazardous Condition

An Arizona case involved an accident which occurred on an icy highway. The court, in determining whether the acts of a governmental body are reasonable, must give due regard to whether (1) the icy condition was general or isolated, (2) there was actual notice of the condition, (3) notice was implied or presumed by the lapse of time of the condition, and (4) a reasonable time for correcting the condition had elapsed after such notice.

There was no recovery, as the mere fact that there was ice on a county highway does not impose liability. The plaintiff must show a duty and a failure to comply. (Walker vs. County of Coconino, 473 P. 2nd 472, Ariz., 1970)

V-6101

RESPONSIBILITY

V-6102

Moral Obligation

Each of us has a moral obligation, along with certain legal responsibilities, to minimize the chance of injury (physical or financial) to our fellow man. Motivations to perform a high standard of work include:

- Pride in a job well done,
- Advancement in responsibility,
- Higher pay,
- Serving the public better,
- A humanitarian interest, and
- Reduce risk of litigation.

Legal Duties

Public bodies have a common law and court-imposed duty to provide and maintain roadways in a safe condition, so as not to expose motorists to undue hazards.

Where existing hazards cannot be eliminated immediately, there is a duty to warn motorists of such hazards.

See AID 6101

The courts have recognized a duty to exercise reasonable care in the initial planning and design of highways.

In some instances, courts have recognized that there is a duty to improve highways where changed conditions are of such a magnitude that the highway is clearly deficient from a safety standpoint.

1 The following case study illustrates this point. A New York driver was reducing speed from 40 M.P.H. to posted speed of 30 M.P.H. It was raining, the vehicle began to skid and a collision occured.

In New York it has been held by the courts that "the state has a duty to the public to keep its highways in reasonably safe condition and the state should place

IMMUNITY

The Need for Compensation (77)

Some engineers and administrators resent tort claims, because they find it difficult to understand the necessary justification of legal action to secure care and compensation for accident injuries. Generally, one is assured only of the critical emergency treatment required at the time of the accident and sometimes not even that. Further treatment and rehabilitation may depend entirely on the personal resources of the injured or the survivors. The poor, and even those in middle income brackets, may have to sue to force funds for care and support from those responsible for the accident or from some insurance companies which deny responsibility and settle only when forced to do so "at the courthouse door."

No one really stated the objections to immunity more clearly than Abraham Lincoln when he said, "It is as much the duty of government to render prompt justice against itself in favor of citizens as it is to administer the same between private individuals."

Contingency Fee Financing of Legal Services (77)

Similaryly, it is difficult for many to understand the employment of the contingency fee as a means of financing the services necessary to prepare and prosecute legal action to recover damages in accident cases. Contingency fee funding may be the only recourse of the poor and many others. The surviving injured and dependents often face lack of care and support. They often turn to contingency fee actions out of sheer necessity.

Discretionary Versus Ministerial Functions

Discretionary acts are those in which there is no hard and fast rule as to a course of conduct that one must or must not take. Ministerial acts are those performed with minimum leeway as to personal judgment and do not require any evaluation or weighing of alternatives before the undertaking of the duty to be performed.

There are several sound reasons for these rules that result in conditional immunity of the state or the public employee. Under the separation of powers doctrine in this country, each coordinate branch of government is vested with certain powers and decision-making responsibilities. Thus, the courts are reluctant to second guess discretionary decisions made by executive bodies.

Moreover, the courts are, at times, thought to lack the necessary expertise to make some judgments that are entrusted to expert bodies having specialized knowledge and understanding of the problems in their own areas.

warning signs on a state highway if circumstances demand...... Ordinarily a defendant is not liable for conditions due solely to the weather, but where the highway becomes more slippery than usual the state may become liable to those injured."

Witnesses testified that the hazardous condition existed prior to the accident. The court concluded that "the state should have been aware of the condition and was negligent because it had not removed the hazard or warned travelers of its presence."

IMMUNITY

Who can be sued?

Sovereign Immunity

V-6103

Sovereign immunity emerged in the United States due to a series of early decisions. The Supreme Court of the United States held that the federal and state governments were immune from suits commenced without their consent. These decisions were based on a misconception of England common law, which was said to immunize the king as sovereign for wrongs committed by his agents because "the king could do no wrong."

In 1946 the United States government waived its immunity from liability in tort and provided for litigation of tort claims against it in federal courts by the Federal Tort Claims Act. This act makes the United States liable under the local law of the place where the tort occurs for the negligent or wrongful acts or omissions of federal employees within the scope of their employment. (76)

See Tort Actions

State Immunity

See AID 6102, Need for Compensation and Contingency Fee Financing

Status of immunity by state summarized in AID 6108

Until recently, state highway departments had little to fear from suits against them for tortious injury to persons or property caused by negligence in the design, construction and maintenance of highways. The states assumed that they had immunity. In the past twenty years, however, this doctrine of sovereign immunity has undergone erosion, legislative modification and in some cases outright abolition by judicial decisions.

Discretionary Versus Ministerial Functions (Continued)

The courts have reasoned that public functions carried out by public officials and employees would be seriously impaired if all their actions were subjected to personal liability. (81)

In summary, the courts are balancing two policies: The need for orderly administration of governmental functions, and the need to compensate victims of injuries resulting from the negligent performance of governmental functions. In order to perform this balancing, the common law formulated the discretionary-ministerial test in the area of personal liability that was later applied in negligence suits brought against the state.

Governmental Versus Propriatory Functions

At the municipal level an important distinction related to immunity is whether governmental as opposed to proprietory functions are involved. In those states where some immunity passes on to municipalities the law has attempted to distinguish between the dual character of municipalities and limit immunity to only governmental or public functions. A municipality's proprietory or private functions are not immune and, therefore, may result in tort liability. (81)

Governmental functions are those which can only be performed adequately by the government. An example of these would be police, fire, courts, and public schools.

Proprietory functions are those which a city performs but which could be performed as well by a nongovernmental organization. As a rule of thumb, where a city derives revenue from a service, this service can be considered a proprietory function (water, gas, electricity, rental of halls, etc.). Courts have generally regarded that the construction and maintenance of public streets, highways, sewers, or other public improvements are proprietory functions.

Case Study - Design Immunity

In Idaho, a highway contractor was sued for negligence on the grounds that an oil slick on the highway section constructed by the contractor caused the plaintiff's automobile to skid and go out of control. The Supreme Court of Idaho felt that when the work of an independent contractor is completed to state specifications and accepted by the owner, the contractor is not liable to a third party.

2 Case Study - In this case New York State was held liable for injuries occurring when a vehicle traveling at 30 mph in a light rain skidded out of control.

The highway had recently been resurfaced with a chip seal. Shortly after completion, it was noticed that the aggragate was being thrown off by traffic and the emulsion was causing slippery conditions. Warning signs had been ordered but none had been placed at the scene.

The court felt it was the responsibility of the state to provide some form of warning for drivers. The state was not immune because it had shown previous knowledge of the condition by ordering the warning signs.

Several mechanisms have been established which reflect the prevailing opinion that a state should assume some responsibility for its negligence by compensating the victims in the case of accidents. Many states have established one of the following.

- The state cannot be sued without its consent.
- Suits may be instituted only in the manner prescribed by statute, often before a special tribunal.
- Suits may be authorized only where the negligence falls within prescribed limits.
- Tort suits based upon general negligence are permitted as if the state were a private person.

Other Jurisdictions and Organizations

The situation for counties varies from state to state, but in most instances counties do not enjoy immunity from tort liability. Corporations and private parties are, of course, completely liable. Municipalities were typically established as corporations and, therefore, never inherited any form of immunity.

There may be municipal immunity for governmental functions.

Discretionary and Ministerial Functions

See detailed discussion

The primary defense to tort liability by state highway departments for design, construction, and maintenance negligence is based on the theory that certain action taken by government is discretionary and, therefore, immune. The exemption from liability for discretionary activity is rooted in the common law, having emerged as a defense in tort suits seeking to hold officials personally liable for their negligence. Persons involved in ministerial acts, however, are generally open to liability suits.

Discretionary functions are those requiring the exercise of independent judgment in arriving at a decision or in choosing a course of action.

Ministerial functions, on the other hand, involve clearly defined tasks. They are performed with minimum leeway as to personal judgment and do not require any evaluation or weighing of alternatives before undertaking the duty to be performed.

Highway design has traditionally been held to be a discretionary function, whereas highway maintenance is generally considered to be a ministerial funtion.

Design Immunity

Discretionary =
Professional judgment

The design of a highway has generally been held to be discretionary because it involves a high-level planning activity with the evaluation of policies and factors. This conclusion, moreover, is supported further by the decisions which hold that design functions are quasi-legislative in nature and must be protected from "second guessing" by the courts, which are inexpert at making such decisions.(76)

Design immunity statutes represent a further effort by legislatures to immunize governmental bodies and employees from liability arising out of negligence or errors in a plan or design where the same was duly approved under current standards of reasonable safety.

Case Study - This case occurred in New York when a tractor-trailer skidded off the 3 highway at the crest of a hill during a snowstorm. The road was slushy and deteriorating. The claim was based on negligent construction, maintenance, and repair of the highway and on failure to erect adequate warning signs of dangerous conditions. Although the Bill of Particulars covered negligence due to snow, slush, and ice on an unsalted and unsanded highway, the court allowed an investigation of the highway banking because there was no prejudice, surprise, or bad faith. Referring to this investigation, the court found that "...the highway was crowned in the center and banked to the west....There is no expert proof that such was improper construction." This lack of expert textimony left the case relying on proof of negligence which was also unfounded. The court found that the standard of reasonable care for this area in northern New York had been met since the road condition had not existed for an inordinate length of time.

The courts have noted exceptions to design immunity where:

- The approval of a plan or design was arbitrary, unreasonable, or made without adequate consideration;
- It contained an inherent, dangerous defect or was defective from the very beginning of actual use; and
- Changed conditions demonstrate the need for additional or remedial state action.

BASES FOR COURT ACTIONS

V-6104

Bases for court actions as a result of accidents are: 1) Tort actions; 2) Basic standards of care; and 3) Nuisance.

Tort Actions

Government agencies, contractors and individuals engaged in work on streets and highways are subject to legal actions under

STANDARD OF CARE

The Concept of Foreseeability *(78)*

The necessity of showing that the results of negligence were foreseeable can sometimes prevent an injured motorist from establishing the liability of a governmental entity. An extraordinary or unlawful use of the road is considered to be unforeseeable.

The defense has been used that a negligent highway design cannot be said to be the proximate cause of injuries inflicted on others by drunken drivers because a governmental entity is not bound to anticipate the behavior of such drivers. This logic is fallacious, however, as there is nothing extraordinary about speeding or drunk driving. But even if there were, it can hardly be said that such use of the roads is unforeseeable. Therefore, it should be concluded that irresponsible driving of a king engaged in daily by thousands of motorists is unforeseeable merely because the law forbids it.

Many courts do not consider foreseeability an essential element in determining liability. Thus, a governmental entity would be liable to a motorist injured as a result of the negligent design or maintenance of a highways, whether the result was foreseeable, such as a collision with a roadside obstacle brought about by slippery road conditions, or unforeseeable, such as a collision brought about by a drunken driver.

the laws of tort liability. A tort is a private or civil wrong or injury (as opposed to a criminal act). The essential factor in a tort liability case is negligence.

Four elements are necessary for every tort action.

All 4 are necessary

- The defendant must have a legal duty to perform.
- The defendant must have failed to properly perform that duty.
- Failure to perform must be a proximate cause of the accident...... A proximate cause produces the injury and, without it, the injury would not have occurred.
- The plaintiff must have suffered damage as a result.

See Causation, p. 61-10

Standard of Care

The basic standard of care required from highway personnel is that of responsible safety under the circumstances. Generally, highway officials must keep the roads reasonably safe for all motorists.

Where hazardous conditions exist which can be removed, the reasonableness of the risk of harm is measured by the following factors:

- The likelihood of harm,
- The severity of harm posed by the condition,
- The usefulness of the condition for other purposes, and
- The burden of removing the condition.

Those responsible for the design, construction, and maintenance of the highways must realize that driver errors will occur. The standard of reasonable safety under the circumstances appears to mean reasonable safety under almost all circumstances. Therefore, highway officials

See AID 6103

AID 6104

NUISANCE

Public Nuisance as a Basis of Liability (78)

Nuisance, unlike common law negligence and breach of statutory duty, is not a type of tortious conduct or behavior. A nuisance is an objective physical condition which invades the rights of the public. When nuisance is the issue, the focal point is the effect of the alleged nuisance, not its cause. The essence of both negligence and breach of duty is a particular act or a series of acts whose performance falls below the expected standard of care. Nuisance is a condition which is continuous or which recurs over a considerable period of time and which invades a public right.

This crucial difference between nuisance and negligence would make nuisance a particularly effective cause of action in a case involving a highway which is lined with roadside hazards, yet was designed in accordance with the best standards of its time. It is immaterial that roadside hazards do not actually obstruct the highways. The cases show that man-made devices near a road will be considered a public nuisance if it poses a threat to travelers. A lack of protective guards around an excavation near the highway has been held to be a public nuisance. Dangerous signs are public nuisances if they endanger travelers.

One of the most familiar instances of public nuisance is a highway out of repair. The absence of suitable roadside barriers or other protective devices has been held to constitute a nuisance. The general rule is that any artificial device, structure, or excavation adjacent to a highway which poses a threat of injury to travelers can be considered a public nuisance.

Case Study - Nuisance

In this case, an automobile skidded on a patch of ice resulting in a collision leading to serious injuries and death. This accident occurred on Suitland Parkway, a Maryland road maintained by the National Capital Park Service. Suit was filed against the United States. In the initial suit, it was held that the United States should have discovered and corrected the unsafe condition. The Fourth Circuit Court of Appeals reversed this decision on the basis that proof of skidding alone did not support the judgment. On remand, the United States was held liable. It was found that an inadequate drainage system had caused the ice to accumulate and that this constituted a nuisance. This indicates that a defectively designed highway can constitute a public nuisance. (Jennings v. United States, 178 F. Supp. 516 D.Md. 1959) are expected to exercise diligence in making the roads safe for travel.

4 Case Study - In California, a wet weather case involving a construction defect brought about the largest out-of-court settlement at that time. The accident occurred when a 19-year old college student hit a slippery area on a freeway, lost control, and plunged down an embankment. The injuries received rendered the student a quadripligic.

The highway had been open less than three weeks and, during that time, approximately 40 similar accidents had occurred in that same general location. Highway department engineers tested and found the coefficient of friction on the road surface was well below the minimim specified in the construction contract. Witnesses observed an oil film on the road caused by seepage from the asphalt shoulders and expansion dividers in the PCC pavement. Water and mud was also observed in the highway. The court felt an acceptable standard of care had not been met.

Design and maintenance are not evaluated in terms of local standards; rather they must meet nationally accepted standards. For example, negligence may be shown by a failure to abide by standard highway manuals. A failure to comply with departmental standard operating procedures will also be considered negligence. When a statute or regulation prescribes certain levels of performance, those statutes or regulations define the lowest standard of care which must be met.

Nuisance

A public nuisance is an unreasonable interference with any right common to the general public. Any manmade device or structure on, or adjacent to, the highway which poses a threat of injury to travelers may be considered a nuisance.

As a tort, nuisance differs from negligence because a nuisance is an objective physical condition, whereas negligence and breach of duty depend on

See AID 6104

AID 6105

NEGLIGENCE

Duties as Related to the Charge of Negligence

Roadside hazards can be fought on the general common law principles of negligence. Public bodies have a common law, court imposed duty to maintain the roads in a safe condition, so as not to expose motorists to any undue hazards. The century old common law duty of maintenance has been construed to require that the areas adjacent to the road, as well as the road surface itself, be kept safe and free from hazards.

To avoid assertions of liability, highway authorities should provide motorists with an unobstructed recovery zone that varies according to speed of traffic and the terrain of the surrounding land. If a government maintains dangerous obstacles or devices on or near the highway, even if they are devices such as guardrails, the courts will hold the government liable for the injuries suffered in collisions with them.

Where existing hazards cannot be eliminated immediately, the duty to maintain the roads in a safe condition embraces the duty to warn motorists of the hazards. However, it is extremely doubtful that a government could fully perform its duty to keep the roads safe and avoid liability simply by posting signs warning that an entire road is dangerous.

Case Study - Limits of Liability (Causation)

In one case the State of California was sued for rape! A woman was raped in the deep grass within a highway right-of-way. The contention was that the state was negligent in performing proper maintenance. This case was successfully defended by the state on the grounds that the injury resulted from an illegal act.

Limitations to the Defense of Contributory Negligence (78)

Foreseeability as a Requirement -- The fact that the plaintiff had not been driving on the right-hand side of the street when he collided with a traffic marker was held not to constitute contributory negligence. The court concluded that it could not be held as a matter of law that a reasonably prudent man would have anticipated that as a consequence of his negligent driving, he would collide with the obstacle, the presence and location of which were known to him. (Young v. City of Camden, 187 SC 414, 198 S.E. 45, 1938)

Violation of Safety Statute Not Negligence Per Se -- It has been held that it is not negligence per se for one to ride on the land adjacent to a highway, in violation of a state statute. Neither is it negligence per se for a motorist to travel on the left-hand side of the street, contrary to the provisions of a city ordinance. (op.cit.)

conduct which fails to measure up to a certain standard. In the case of nuisance, plaintiffs may ask for an injunction to remove the nuisance, in addition to a suit for damages.

A strong argument could be made that slippery roads constitute a nuisance.

5 Case Study - In Washington, D.C. icy conditions created by inadequate drainage facilities caused an accident. The court found that frequent users of the highway had been aware of the condition and that the agency responsible for maintenance should also have been aware of the situation.

The court further found that the existence of the improper drainage facility had created a condition that was a nuisance, that the patch of ice was the cause of the injuries. Since the government could have corrected the problem, it was liable.

NEGLIGENCE

V-6105

Negligence is the omission of an act which a reasonable man would do, or the commission of an act which a reasonable and prudent man would not do.

The primary tests used to establish liability for negligence are:

- Is it breach of a legal duty; and
- Is the breach of duty a directly contributory cause to the injury that resulted (proximate cause).

A second test involves defining the standard of care which would be exercised by a hypothetically reasonable and prudent man. If the performance of those persons responsible for design and maintenance fall below this standard, then negligence is indicated. Any of the following situations may be the basis of negligence.

- Misfeasance

  - performing a lawful act in an improper manner

[redacted]

Limitations to the Defense of Contributory Negligence (Continued)

Negligence of Agency as Intervening Cause -- *The negligence of a governmental agency may exonerate a driver of the consequences of his own misconduct, and overcome the government's defense of contributory negligence. An intervening cause, such as the prior negligence of a governmental entity in the design or maintenance of its highways, is one which comes into active operation in producing the result after the negligence of one against whom the defense of contributory negligence is to be employed.*

Lower Care Required of Motorist in an Emergency -- *If the driver exercised some care, he may be found to be free of contributory negligence. In an emergency, even a failure to observe caution signs will not amount to contributory negligence. Where one is confronted with a sudden emergency which is not of his own making, he is not held to the same degree of prudence which might otherwise be expected.*

Assumption of Risk as a Defense (78)

A traveler must know of the specific hazards he faces. If he knows of the precise condition of a road, e.g. that it is slippery from oil or ice, he may be held to have assumed the risk of injury by traveling on it. However, it is not an assumption of the risk for one to travel on a road which he knows to be in a generally defective condition.

In one case the plaintiff had to travel at night on an unlighted dirt street which he knew to be under repair. Despite his exercise of reasonable care under the circumstances, he was injured. The court held that he had not assumed the risk of injury from even the readily apparent dangerous conditions, including excavations and piles of sewer pipe, because he had no choice but to use the street. (Broadway v. King-Hunter, Inc.)

Case Studies - Notice

In Kansas, in 1967, a 4-lane divided highway was constructed in conformance to design standards then existing. Water accumulated on the road surface and five accidents occurred at a specific location during inclement weather. A sixth accident on a rainy day at the same location resulted in personal injuries and the loss of an auto.

In the resulting court case, the state was found liable for defects in construction. By statute, the state has 5 days to act once given notice. Five prior similar accidents established the issue of notice and there was a clear duty to place warning signs until repairs could be made. The absence of such signs resulted in a $450,000 judgment against the state. (493 P. 2nd 236 Kan., 1972)

- Nonfeasance

  - the omission of some act which ought to have been performed

- Malfeasance

  - committing an unlawful act

The following negligence case illustrates nonfeasance. In Iowa an accident occurred when a car skidded on a railroad overpass, went out of control and crashed. The driver remains a paraplegic.(77)

Testing indicated that the bridge deck was frost-coated and slippery. The court found the condition had been aggravated by an unusual type of seal coat on the deck and held that the state was negligent for not providing countermeasures for the frost conditions.

The failure to conform to a safety statute is often defined as negligence, per se.

The courts have been generous in allowing plaintiffs to present evidence of negligence including:

See AID 6105

- Variance from standard engineering manuals and publications,
- Proof of accidents at the same location, and
- The testimony of expert witnesses.

It should be noted that remedial conduct (corrective action taken after an accident) is generally not admissible to show negligence but it may be admissible to demonstrate feasibility of taking action.

Negligence cases can be built around causation, contributory negligence and notice.

Causation

A proximate cause is one which, in natural and continual sequence, produces the

A similar case in California resulted in a hung jury. The plaintiff's vehicle skidded out of control when it hit a muddy spot on a mountain highway. The mud had been tracked on the highway by state maintenance crews in the process of cleaning up a mud slide. No warning signs or barriers advised motorists of the condition. As a result of the accident, the plaintiff was rendered a quadriplegic. After several days of deliberation, the jury was hopelessly deadlocked at 6 in fabor of the plaintiff and 6 in favor of the state. A mistrial was then declared. Because the state felt that it has presented its best case and the plaintiff did not particularly wish to incur the added expense of retrying the case although he was prepared to, the case settled at $150,000. From these facts, if the case had been retried, a plaintiff's verdict of over 1/2 million dollars could easily have resulted.

injury and without which the result would not have occurred.(78)

Another widely used definition treats proximate causation in terms of the consequences of negligence. The injury must be the natural and probable result of the negligent act or omission and be of such a character as an ordinarily prudent person ought to have forseen as likely to occur as a result of the negligence, although it is not essential that the person charged with negligence should have foreseen the precise injury which resulted from his act.

6 Case Study - Proximate causation must be proven in order to render an engineer or the state liable for defective highway design. The continuing duty owed by independent contractors is difficult to establish.

In New York, an automobile went off the paved portion of the highway and crashed into a blockhouse approximately four feet off the paved portion of the road. Improper grading of the road was one alleged defect. It was not proven, however, that state negligence was the proximate cause of the accident. The state appellate court upheld the decision on appeal.

The principle of concurrent causation was developed many years ago and is now generally accepted. It is not necessary to find that negligence was the exclusive cause of the accident, but rather that it was "a proximate cause" which combined with the concurrent negligence of the driver to cause the accident. The fact that neither party could reasonably anticipate the occurrence of the other concurrent cause will not shield the agency from liability so long as its own negligence was one of the causes of the injury.

Furthermore, when the proximate cause of an injury is the negligent act or omission of two or more persons acting independently, both are liable and the degree of culpability is immaterial. Therefore, a governmental body cannot escape liability by showing that its negligence was only a minor departure from reasonable care whereas the negligence of a motorist involved in an accident was "gross," "wanton," or "reckless." Only when the negligence of a driver was the sole cause of the injuries is a court prevented from imposing liability on a public body.

Contributory Negligence

One defense that is often cited by highway agencies is that the driver shared a responsibility for the accident and injuries that resulted through his carelessness are contributory negligence.(76)

There are several factors which the courts have repeatedly focused on to support a finding of contributory negligence by a driver. The most significant of these factors are :

- Reckless driving
- Familiarity with a defective highway, and
- The visibility or obviousness of a road defect.

Case Study - In this case the claimant was driving up an incline of a three-lane highway. Cresting a hill he observed that the road narrowed to two lanes. He braked, skidded on the wet pavement, fishtailed to the opposite side of the road and collided with an oncoming vehicle.

The court found that, while the state was negligent in designing and signing the highway, there was adequate notice of a hazardous driving condition ahead and a reasonable and prudent person would have been prepared for the possible hazard.

Nearly all courts have developed a healthy dislike for the defense of contributory negligence. Because the defense unfairly penalizes motorists whose driving was only slightly negligent, and because it probably does not deter accidents, the courts have evolved a number of limitations to the use of contributory negligence as a bar to governmental liability for highway hazards.

See AID 6105
Limitations to Defense
of Contributory Negligence

- Some courts have held that foreseeability is a necessary element of contributory negligence.
- The scope of contributory negligence as a defense has been further curtailed by the courts' reluctance to find that a violation of a safety statute by a motorist is, in and of itself, negligence.
- The courts have also excused the poor driving of a motorist by finding that the negligence of a governmental entity in not performing its duty to keep the roads safe was an "intervening cause," sufficient to exonerate the driver.
- Another approach to the problem of contributory negligence involves an analysis of the situation confronting a driver immediately before his accident. If he was faced with an emergency, the courts are inclined to apply a lower standard of care than that which is ordinarily expected of motorists.

See AID 6105 Assumption of Risk

Notice

The duty to correct a dangerous condition or otherwise take appropriate action arises when notice is received about the hazard. In some states the agency must have notice of the condition for a requisite statutory period, such as five days.

Notice is generally considerd to be received once a report is filed with any agency of the jurisdiction having responsibility.

Under the concept of constructive notice, the duty to act may arise when the agency should have known of the existence of a dangerous condition. It may not be necessary to prove that actual notice was given. A highway agency has a responsibility to inspect its roadway and

See case study that follows.

EMPLOYEE LIABILITY FOR NEGLIGENCE

Because of this doctrine of state immunity, many litigants were compelled to find another means of redress in the courts for injuries caused by highway defects. Claimants as a poor second choice were relegated usually to suing the highway official or employee in his personal capacity for negligent conduct of his duties. (82)

Several distinctions exist between personal liability and state liability. First, because the state acts through its agents and employees, state liability is based on the doctrine of respondent superior--that is the master is liable for the acts of his servants. It follows that where the public employee performs a negligent act that does not fall within an exception to liability, the state agency may be held liable in a tort suit.

The law of public official and employee personal liability, on the other hand, does not apply the doctrine of respondent superior to officials and employees. For example, a supervisor may not be held personally liable for the negligent acts of his subordinates. The supervisor would be accountable only if he personally participated in the negligent conduct or was negligent in the selection of the employee.

Moreover, it may be noted that the public official or employee is not protected by any umbrella of state or sovereign immunity. In the absence of statute, the general view is that the public official or employee may be held personally liable for his negligence even though the state is immune from suit or liability for the negligence of its agents. Sovereign immunity and the immunity of state officers and employees are different legal concepts with different origins and purposes.

The two areas of law are similar in that the courts have developed certain rules or tests to limit liability to those areas in which it is thought proper to impost liability for negligent conduct. Neither the liability of the state nor of the public official is determined exactly in the same manner as if the suit were brought against a private person or corporation. Thus, states and officials or employees, although there are exceptions, are generally held not liable for performing negligently their discretionary functions or activities (performing duties that require the exercise of judgment and discretion). Where employees are involved, the general rule is that they are not liable for negligence committed during the exercise or performance of an official duty discretionary in nature. The rule of privilege does not apply, however, if the official was acting out of malice, committing an intentional tort, or exceeding his jurisdiction (such as by trespassing on the property of another).

traffic control systems periodically. Therefore, there is an obligation to be aware of defects which have existed over a reasonable period of time.

7 Case Study - A truck skidded off the highway and a claim was filed against the Department of Highways. It was denied on the ground that (a) the defect had not been created through negligence and (b) the department had no notice of the condition. This verdict was upheld in the circuit court.

However, the Court of Appeals found that, since the highway had been patched, seven accidents had occured and that evidence revealed the bituminous sealing had begun to flake off shortly after the repair. This exposed the primer coat and allowed the surface to become slippery when wet. For eight years prior to the patching no accidents had occurred at this spot. The court felt that, although no actual notice was present, the defect had been shown to exist for a sufficient period and failure of the department to discover and correct the problem constituted negligence. The court said that although no actual notice was present, ".... circumstances may have been such that knowledge was imputed or presummed."

LIABILITY

V-6106

Potential Targets of Suits

There are several major potential defendants in liability suits involving highways.

- The federal government
  - usually not liable as it performs discretionary functions
- The state and its subordinate jurisdictions
  - liable in varying degrees
  - some states still maintain their sovereign immunity

- Government officials
  - may be personally liable
- Contractors and utility companies
  - completly liable for negligent acts or omissions
- Contractor and utility company personnel
  - personally liable for negligence

The following case involved an
8 interpretation of a West Virginia statute imposing liability for a roadway being out of repair. It established the general rule that, regarding municipal corporations, snow and ice alone do not constitute a defect. The court cited a Kansas statute and similar interpretation as a basis. The rule, according to the court, was stated as such: "In order to establish liability based upon a defect in a street or highway of such nature for the street to be considered out of repair, there must be an accumulation of snow and ice amounting to an obstruction..." The court also cited an earlier case that indicated that the word repair as used in the statue included an obstruction on the highway as well as defects in it and that, although ice and snow may render a street out of repair, there must be an accumulation amounting to an obstruction before it comes within the purview of the statute.

Social Welfare Doctrine

Liability may well result even where all the general "standards of care" are met because of the recognition of a social need and the sympathy of juries. Society has entered an age of liability in which a social welfare doctrine has emerged which insists upon societal protection for all people. There has been a snowball effect of law which can be described as more and more people using more and more products, realizing that they can sue if dissatisfied or injured. Lawyers taking these cases have been winning and are becoming more educated

PROTECTION FROM LIABILITY

The Defense of Insufficient Funds

In some tort liability cases we have seen the argument put forth that the highway agency did not have sufficient funds to perform the work necessary to correct the alleged defect. This argument in and by itself has generally been held to be irrelevant.

The only basis for bringing funds into the picture as part of the defense is to show the following.

- The agency has an effective inspection program and processes accident records and complaints in such a manner that it is aware of the defects and hazardous conditions that exist on its road system.
- The deficiencies noted are analyzed and the corrective action to be taken has been prioritized on the basis of both the degree of hazard and the resources needed to correct the deficiencies.
- That within the resources available, the agency is proceeding to correct these deficiencies in their order of assigned priority.
- For those hazardous conditions which it has not been able to remedy, appropriate warnings and other traffic control measures have been taken to protect the public.

When the agency can demonstrate that each of these steps is being taken, then it has an effective program. It is doing what reasonable and prudent men would do. It is performing in the best way possible within the resources available, taking care of the worst and most easily correctable hazards first. The fact that it has not worked its way down to a lower priority item is a legislative function. The agency is doing the most it can with the funds apportioned to it.

Records

To establish that the burden of reasonability has been met it is necessary to support your decisions by a fully articulated and documented administrative record. Law cases are based upon subtle detail and distinctions, and it is the evidence which establishes the record. An administrator acts and his actions are judged by this record. (Road Review League v. Boyd, 270 F, Supp. 650, N.Y., 1967) in this type of suit. This has resulted in more people exercising their rights to sue.

To pay for the needs of injured parties a "deep pocket theory of justice" has been created. This theory maintains that he who has the deepest pocket (most money) should be the most responsible. The conclusion is an obvious one—government has the most resources so should be the most liable. Corporations are next in line.

PROTECTION FROM LIABILITY

See AID 6107

Highway personnel must anticipate lawsuits in the event of an accident or other grievance suffered by an injured citizen. It is important to demonstrate the existence of an effective program. To prevent or minimize such litigation, and to help defend lawsuits, the following steps are recommended:

- Know and comply with nationally accepted engineering standards and practices.
- Inspect at frequent intervals with a view to detecting and immediately correcting deficiencies in traffic control.
- Protect motorists and pedestrians against hazardous conditions.
- Provide warning devices at hazardous locations.
- Document all actions taken on or related to traffic controls that are placed in effect at the work site.

9 Case Study - The Kentucky Department of Highways maintenance crews were in the process of cleaning drainage ditches when a vehicle skidded on a muddy section of the highway. The mud had been deposited on the road during the cleaning operation. The court held that the state's flagmen and signs were adequate warning of the hazardous condition ahead. The state, therefore, was not liable.

CONCLUDING REMARKS

We have cited several court cases as examples and to support the material covered during this session. For every case which one may bring up to make a point, someone may cite another case which seems to contradict that point. We have admittedly been biased in emphasizing those cases in which the defendants, both highways agencies and their contractors, lost. There are many other cases which could have been cited in which they have been successful in their defense.

The conclusion which one reaches is simply this. If you do a good job, you will win most of your cases. There will always be a few where the social welfare concept of justice or the emotional involvement of a jury will work against you. The converse is also true, however. If you do a poor job, your organization will lose most of the cases brought against it.

One point is most important to remember. Simply doing a good job is not sufficient. You must be able to prove in a court of law that you have done a good job. To accomplish this, adequate documentation is essential. Agency lawyers tell us that for each time when such documentation can be used against the agency, there are ten times that it can be used as the basis for its defense. You must have projects logs and inspection reports that show what you have done, when you did it, what was found during inspections and the corrective action taken. You must document that your performance is that of a reasonable and prudent man.

Documentation for Protection

Since it is not known when an accident will occur, the key to defending cases in courts of law is advanced preparation. Highway personnel and their contractors should maintain a careful record of job-related activities so they may document their efforts to minimize or eliminate potential hazards at the worksite. The record system should reflect priorities and a planned safety program. If corrective actions are supported by proper records, the chances for winning cases are greatly enhanced.

The following steps are recommended as a means of establishing effective project documentation.

- Maintain up-to-date engineering drawings
- File all pertinent memoranda and correspondence
- Reference standards and specifications
- Perform and document inspections
- Follow all safety regulations
- Document all instructions to contractors or subcontractors
- Take photographs at key project stages and for unusual situations

In summary, the steps which can be taken to protect the individual and his organization from liability are:

- Do your job well;
- Keep up with the development of technical information in your field and maintain a high level of competence in traffic control procedures and techniques;
- Recognize that the highways are there to serve the motorists; and
- Document that you are doing your job well.

AID 6108

STATUS OF THE DOCTRINE OF SOVEREIGN IMMUNITY BY STATE

The doctrine of sovereign immunity originated in England and has since been ingrained in the Common Law of every state. The doctrine exists in each state unless legislatively or judicially abrogated. Many of the states have chosen to affirm the doctrine by Constitutional provision, statue, or judicial decision. Thirty states have Constitutional provisions relating to sovereign immunity. These provisions fall into two categories, permissive and absolute. The permissive provision leaves the deicision of whether to abrogate the doctrine and to what extent, in the hands of the legislature. The mandatory provision specifically decrees either that the state is absolutely immune from suite and the legislature is prohibited from abrogating the doctrine, or that the state is not immune and the doctrine is now abrogated. (83)

The states have chosen several ways to handle the problem of sovereign liability.

One method is to simply rely on the doctrine of sovereign immunity ex-lusi clusively with no remedy for the injured party. Under the Common Law doctrine the state's consent to be sued is needed.

Delaware
Maine
Maryland
Louisiana
Michigan
Mississippi
Oklahoma

The second method employed is to maintain sovereign immunity while at the same time setting up legislative claims boards that provide remedies for injured parties. Suits that are prohibited by the doctrine are heard by the claims board which then turns over its recommendations to the legislature for action. The board findings are not binding on the legislature and there is no judgment as such rendered against the state.

Alabama
Arkansas
Connecticut
Georgia
Kansas
Missouri
North Carolina
South Dakota
Virginia
West Virginia
Wyoming
**Pennsylvania*
**South Carolina*

**Contracts only*

The third method can be divided into two categories. The first category includes those states that have abandoned the doctrine of sovereign immunity and have left the remedy for injuries solely to the courts.

Alaska
Arizona
Hawaii
Indiana
Montana
New Jersey
New Mexico
New York
Oregon
Utah
Washington

The second category includes those states which have legislatively created claims boards but allow the claimant to seek further relief via judicial proceedings if the administrative relief sought proves inadequate. The doctrine of sovereign immunity has been abrogated in these states judicially and/or legislatively but the most popular method has been through tort claims acts which 20 states have adopted. These acts have the effect of reinstating sovereign immunity because by providing for liability in in specific instances, it makes the state immune by implication in the areas not specified.

California
Idaho
Illinois
Iowa
Nebraska
Ohio

Nevada fits under the first category in tort and under the second in contract. Colorado is the reverse.

The remaining states employ a combination of methods in that they abolish sovereign immunity in tort cases while maintaining it in contract, such as

Florida
Rhode Island
Tennessee
Texas
Vermont

Or, they annul sovereign immunity in contract while keeping it in tort.

Kentucky
Massachusetts
Minnesota
New Hampshire
North Dakota
Wisconsin

LEGAL CASES ENTERED THROUGHOUT SESSION

(1) Stern vs. State N.Y.

(2) Veit vs. State

(3) Tetreault vs. State 269 N.Y.S. 2nd 812, N.Y. 1966.

(4) Baldwin vs. State, Cal. January 3, 1972

(5) Jennings vs. U.S. 207 F. Supp. 143, D.C., M.D., 1962.

(6) Cruz vs. State N.Y., 1972

(7) Freeport Transport, Inc. vs. Commonwealth, Department of Highways, 408 S.W. 2nd 193, Kentucky, 1966.

(8) Christo vs. Dotson, 155 S.E. 2nd 571, W.Va., 1967.

(9) Commonwealth, Department of Highways vs. Brown, 346 S.W. 2nd 24, Kentucky, 1961.

6101

- RESPONSIBILITY
  - IMMUNITY
    - BASES FOR COURT ACTIONS
      - NEGLIGENCE
        - LIABILITY

6102

RESPONSIBILITY

- Moral Obligations
- Legal Duties

6103

IMMUNITY

- Sovereign Immunity
- State Immunity

- Other Jurisdictions
- Discretionary & Ministerial Functions
- Design Immunity

6104

BASES FOR COURT ACTIONS

- Tort Actions
- Standard of Care
- Nuisance

6105

NEGLIGENCE

- Causation
- Contributory Negligence
- Notice

6106

LIABILITY.

- Potential Targets of Suits
- Social Welfare Doctrine

SESSION GUIDE

SESSION: 71. COURSE EVALUATION

SESSION OBJECTIVES:

During this session the objective is twofold: first to evaluate the participants` grasp of the major points presented in the course, and second give the participants an opportunity to evaluate the course.

REFERENCES:

Sessions 11-61

CONTENT:

A check list evaluation of the course for participants to rank each session on a scale from 1-10.

TEACHING METHODS AND AIDS:

Written Test

Evaluation

Discussion

RESOURCE MATERIAL:

A-7101. COURSE EVALUATION QUESTIONNAIRE

ADDENDUM 8101

COURSE LOCATION: ______________________________

SKID RESISTANCE MEASUREMENTS AND DESIGN

Course Evaluation Questionnaire

INSTRUCTIONS:

In order to continue to refine this course and improve the effectiveness, please furnish your evaluation of each course component. For each session presented indicate whether the material should be given more or less time or emphasis by circling the appropriate letter ("1" less, "S" same, "M" more). Give each session an integer numerical (QUAL.) grade using the scale zero to ten ("0" very poor, "5" O.K., "10" excellent). Similarly, provide scores for visual aids, the Participant Notebook, individual instructors and the overall course. Indicate how well session objetives (OBJ), as stated at the beginning of each session, were met by using the same zero to ten rating scale.

ADDENDUM 7101

Course Evaluation Questionnaire, Continued

NO.	SESSION TITLE	TIME	QUAL	OBJ.	COMMENTS
	MOVING AND SLID SHOWS				
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
___	___	L S M			___
GENERAL ITEMS					
Participant Notebook		L S M			___
Visual Aids		L S M			___

Instructors: ___

___

___

OVERALL COURSE L S M ___

Did you benefit from participating in the course? Explain how. ___

___

___

Other Comments: ___

___

___

ADDENDUM 7101

Course Evaluation Questionnaire, Continued

NO.	SESSION TITLE	TIME	QUAL	OBJ.	COMMENTS
33	FACTORS AFFECTING SKID RESISTANCE - SEASONAL, CLIMATIC, VEHICULAR, SPILLAGE, & OTHERS.	L S M	☐	☐	
41	RESTORING SKID RESISTANCE - OVERLAYS	L S M	☐	☐	
42	RESTORING SKID RESISTANCE - GROOVING AND TEXTURING	L S M	☐	☐	
51	THE USE OF SKID TEST DATA TO ENHANCE THE DESIGN OF NE PAVEMENTS AND THE DEVELOPMENT OF SPECIFICATIONS FOR SKID RESISTANT PAVEMENTS.	L S M	☐	☐	
52	DESIGN OF NEW PAVEMENTS	L S M	☐	☐	
53	TEXTURING NEW PAVEMENTS: Grooving, Metal Tines, Burlap Drag, Washing away mortar, brushing, etc.	L S M	☐	☐	
61	LEGAL IMPLICATIONS OF HIGHWAY SKID RESISTANCE	L S M	☐	☐	
71	COURSE EVALUATION	L S M	☐	☐	
72	COURSE SUMMARY AND CLOSING	L S M	☐	☐	

NO.	SESSION TITLE	TIME	QUAL	OBJ.	COMMENTS
11	INTRODUCTION TO COURSE	L S M	☐	☐	
12	THE SKID ENVIRONMENT	L S M	☐	☐	
13	FRICTION DEMAND	L S M	☐	☐	
21	WET PAVEMENT ACCIDENT REDUCTION	L S M	☐	☐	
22	DETECTION OF SLIPPERY CONDITIONS - FEEDBACK FROM ACCIDENTS, CITIZEN COMPLAINTS AND VISUAL INDICATIONS	L S M	☐	☐	
23	DETECTION OF SLIPPERY CONDITIONS - SKID TESTING	L S M	☐	☐	
24	CALIBRATION AND CORRELATION	L S M	☐	☐	
31	FACTORS AFFECTING SKID RESISTANCE - MATERIALS	L S M	☐	☐	
32	FACTORS AFFECTING SKID RESISTANCE - PAVEMENT	L S M	☐	☐	

SESSION GUIDE

SESSION: 72. COURSE SUMMARY AND CLOSING

SESSION OBJECTIVES:

During this session the main points of the course will be summarized and the closing ceremonies conducted.

REFERENCES: Sessions 11-66.

CONTENT:

Summary of the Course and Test Evaluation.

Closing Ceremonies and Awarding of Certificates.

TEACHING METHODS AND AIDS:

Discussion - Summarization

Guest - Award Certificates

RESOURCE MATERIAL:

A-7201. Highlights of Skid Resistance Measurements & Design Course

ADDENDUM

HIGHLIGHTS OF SKID RESISTANCE MEASUREMENTS & DESIGN COURSE

Identification of the causes of pavement slipperiness.

Definition of skid resistance.

Characteristics of a skid resistance pavement.

Adhesion and hysteresis.

Wet-weather accidents.

Areas of highest accident involvement.

Wet time criterion.

Purpose of accident records.

Users of accident data.

Methods of detecting slippery conditions.

Minimum information to be included on accident forms.

Features to be contained in accident data system.

Skid testing methodology.

ASTM method E-274.

Polish resistance aggregates.

Types of rock.

Macrotexture.

Microtexture.

Importance of paving materials in skid resistance. Calcareous and other polish susceptible aggregates.

Pavement wear.

Skid resistance - Bituminous pavements.

Skid resistance and studded tires.

ADDENDUM 8201 (Continued)

Hydroplaning

Seasonal variations in skid resistance.

The effects of road contamination on skid resistance.

Open graded asphalt friction course.

Dense graded asphalt friction courses.

Asphalt sprinkle treatment for skid resistance.

Grooving as a method of improving skid resistance

Longitudinal grooving.

Transverse grooving.

Limitations of grooving.

Less used methods of restoring skid resistance.

Design criteria for skid resistant pavements.

Finishing of plastic concrete pavements.

Plastic grooving

Methods of texturing concrete pavements.

Legal implications of highway skid resistance.

Sovereign immunity.

Reasonable care.

Negligence.

Contributory negligence.

Comparative negligence.

Deep pocket theory.

Advisory signing as a technique in meeting general duties.

Trend in legal liability in transportation.

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